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(54) **DENDRITE-RESISTANT BATTERY**

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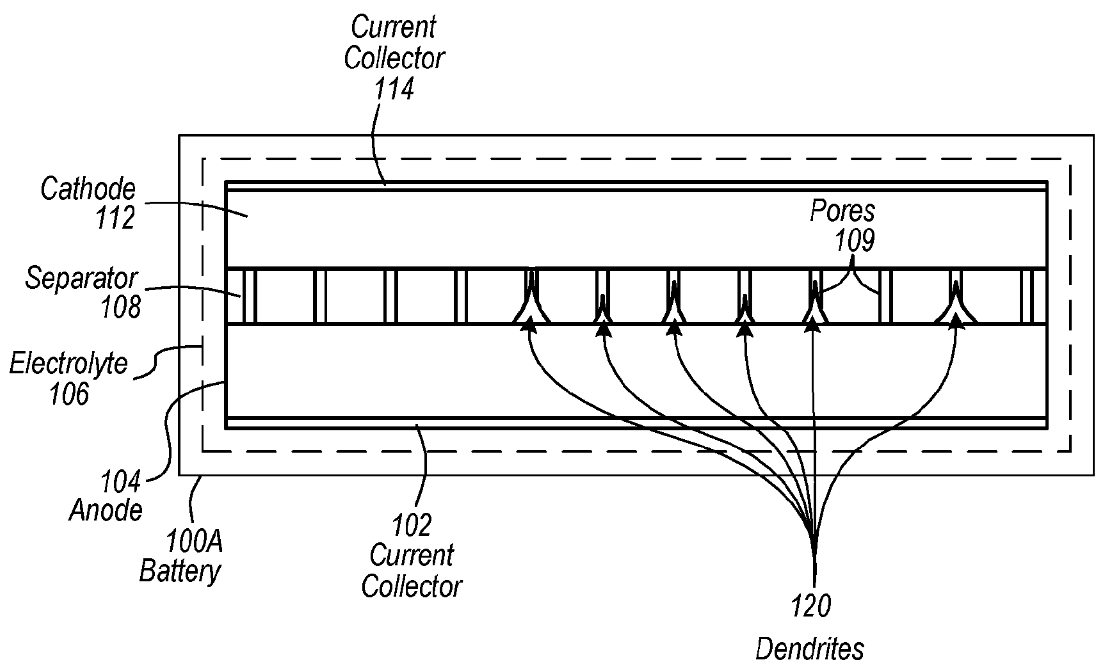
(57) **ABSTRACT**

An apparatus includes a first electrode, a second electrode, and a porous layer positioned between the first electrode and the second electrode. The porous layer resists dendrite growth from the first electrode through the porous layer to the second electrode. The porous layer includes a plurality of pores sized to permit ionic transport through the porous layer and to resist dendrite growth through the porous layer.



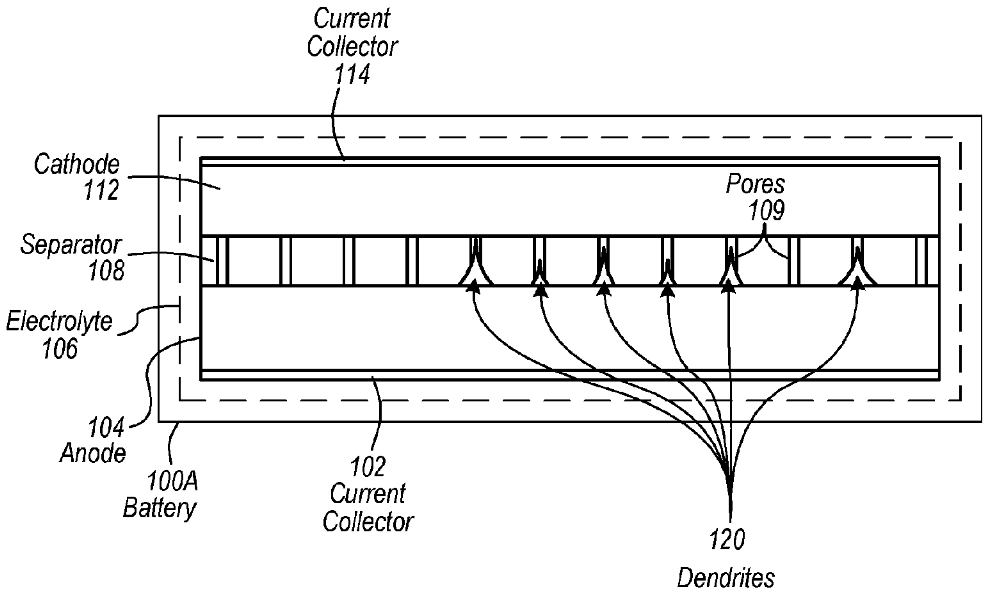

Current Collector 114
Cathode 112
Pores 109
Separator 108
Electrolyte 106
104 Anode
100A Battery
102 Current Collector
120 Dendrites

FIG. 1A

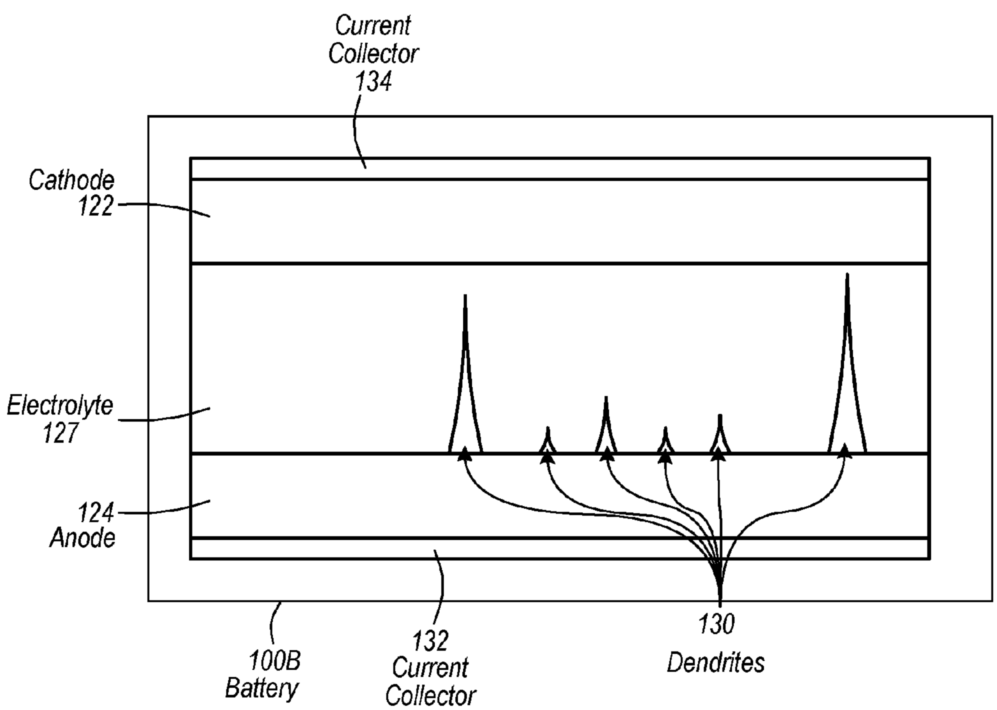

Current Collector 134
Cathode 122
Electrolyte 127
124 Anode
100B Battery
132 Current Collector
130 Dendrites

FIG. 1B

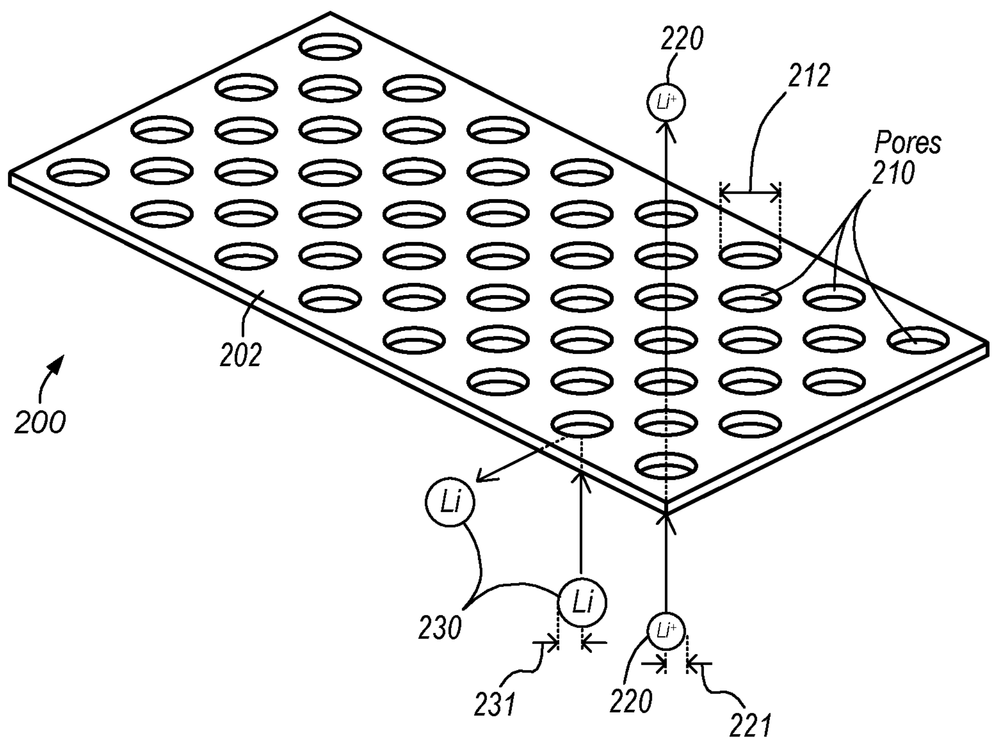


FIG. 2

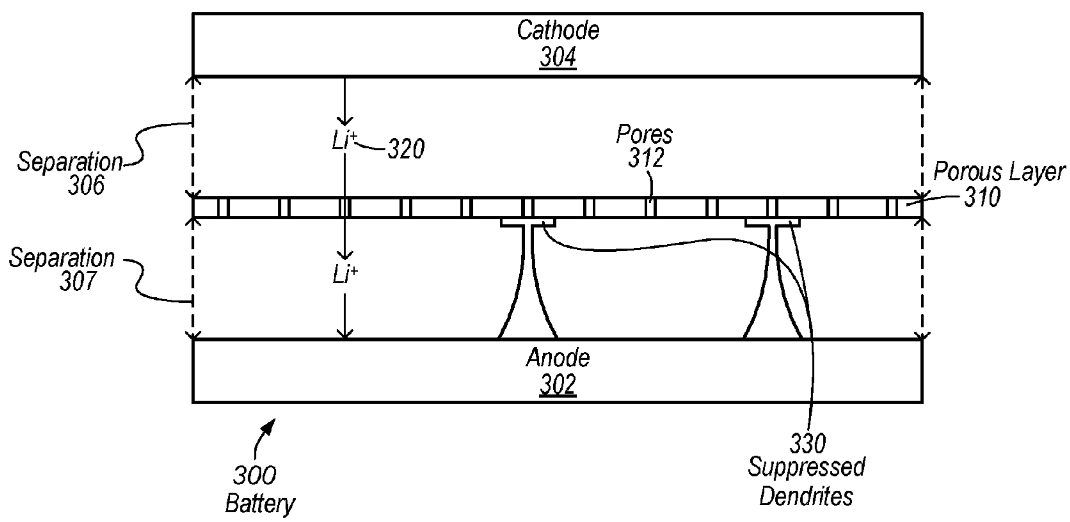

Cathode
304
Separation
306
Li+
320
Pores
312
Porous Layer
310
Separation
307
Li+
Anode
302
300
Battery
330
Suppressed
Dendrites

FIG. 3

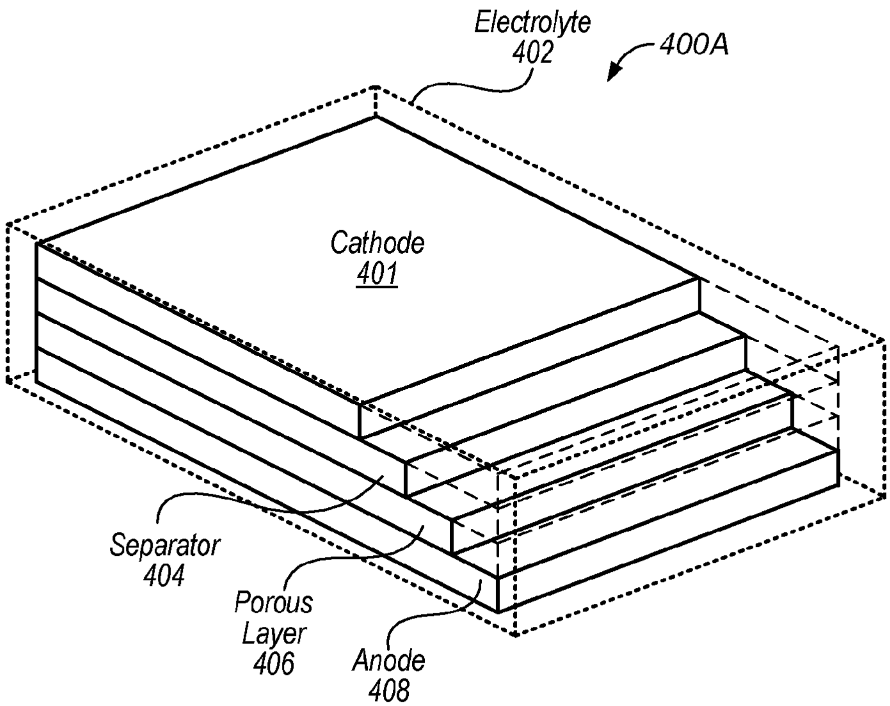

400A
Electrolyte
402
Cathode
401
Separator
404
Porous
Layer
406
Anode
408

FIG. 4A

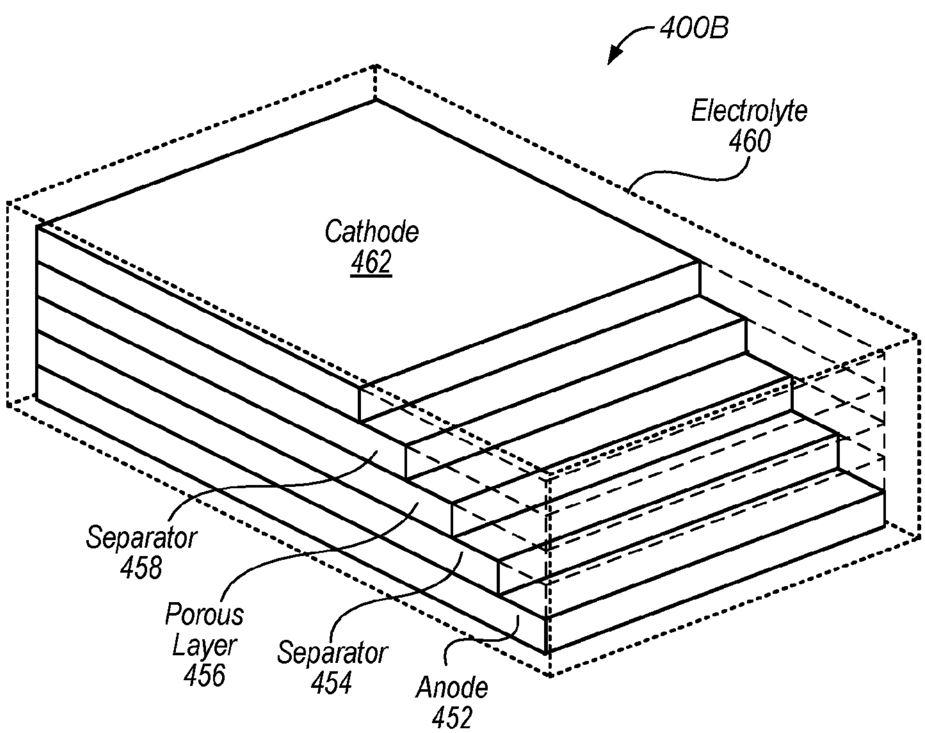

400B
Electrolyte
460
Cathode
462
Separator
458
Porous
Layer
456
Separator
454
Anode
452

FIG. 4B

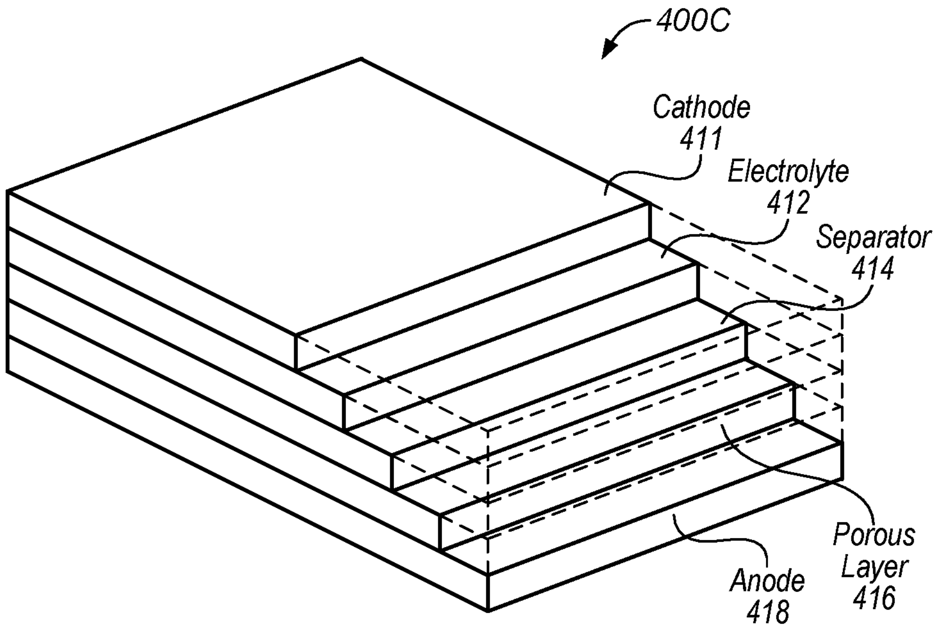

400C
Cathode
411
Electrolyte
412
Separator
414
Porous
Layer
416
Anode
418

FIG. 4C

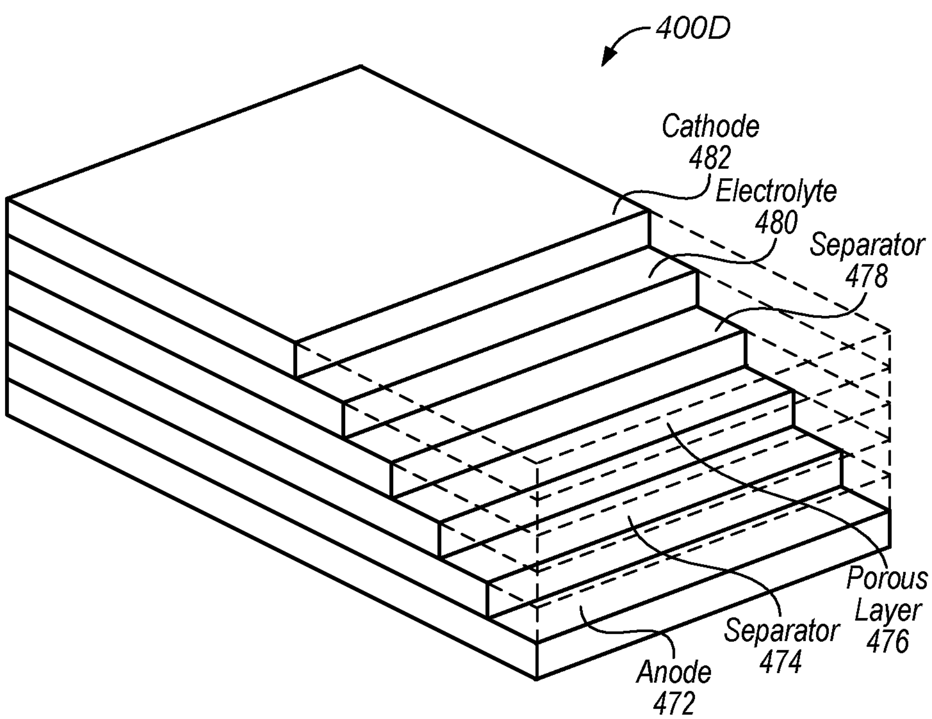

400D
Cathode
482
Electrolyte
480
Separator
478
Porous
Layer
476
Separator
474
Anode
472

FIG. 4D

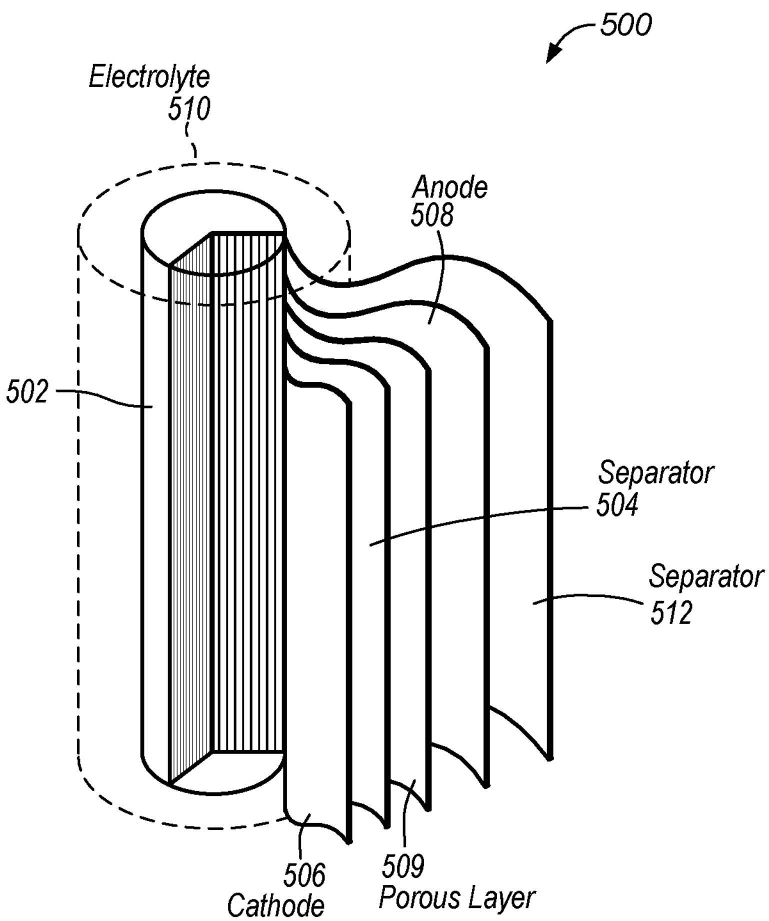

500
Electrolyte
510
Anode
508
502
Separator
504
Separator
512
506
Cathode
509
Porous Layer

FIG. 5

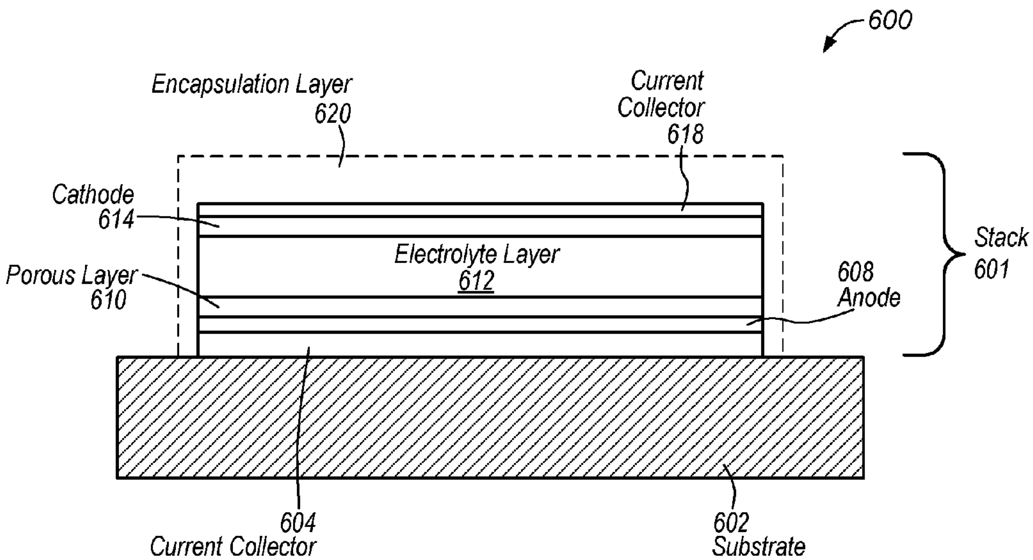

600
Encapsulation Layer
620
Current
Collector
618
Cathode
614
Electrolyte Layer
612
Porous Layer
610
608
Anode
Stack
601
604
Current Collector
602
Substrate

FIG. 6

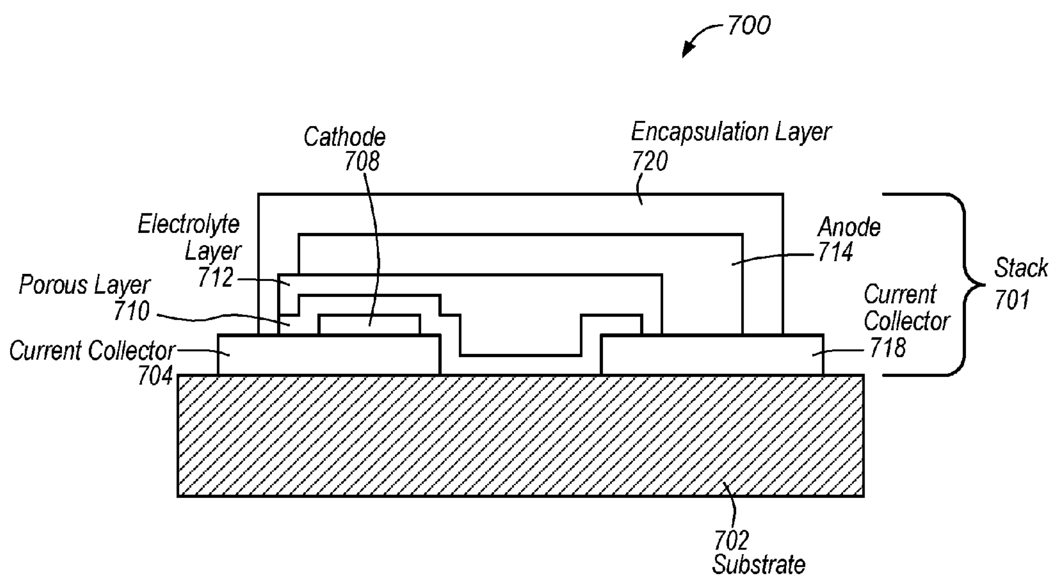

700
Cathode
708
Encapsulation Layer
720
Electrolyte
Layer
712
Anode
714
Stack
701
Porous Layer
710
Current
Collector
718
Current Collector
704
702
Substrate

FIG. 7

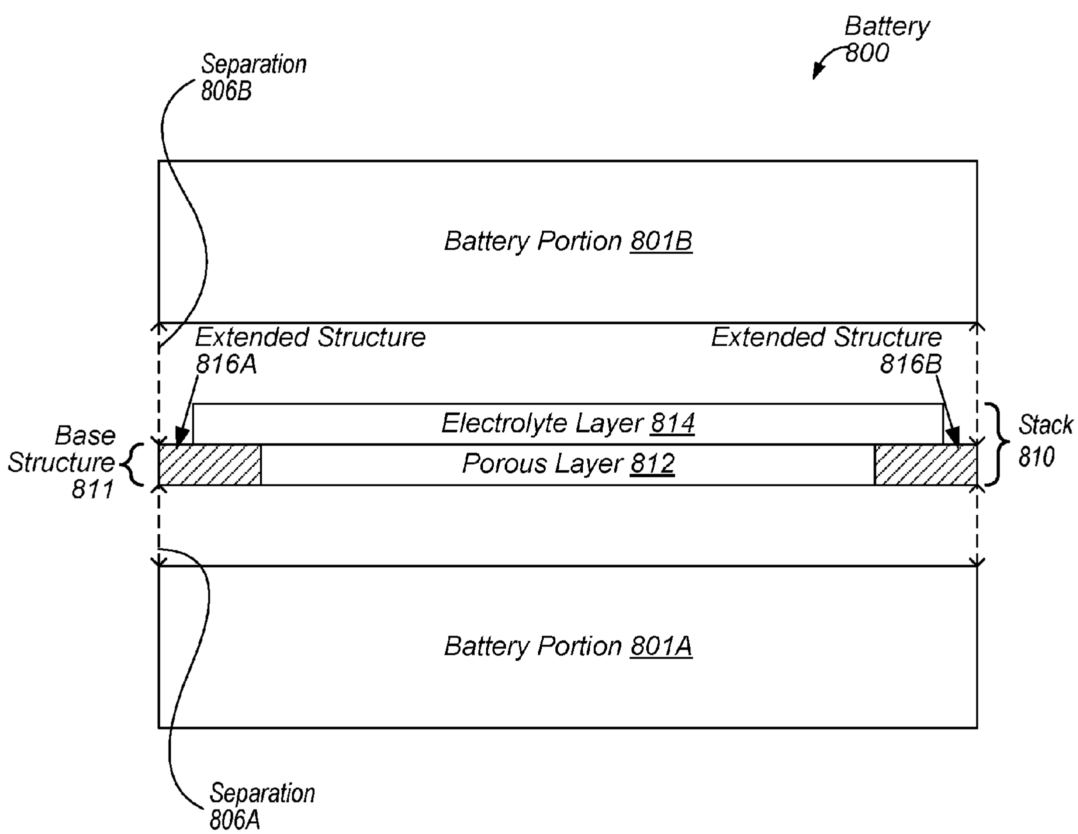

Battery
800
Separation
806B
Battery Portion 801B
Extended Structure
816A
Extended Structure
816B
Electrolyte Layer 814
Stack
810
Base
Structure
811
Porous Layer 812
Battery Portion 801A
Separation
806A

FIG. 8

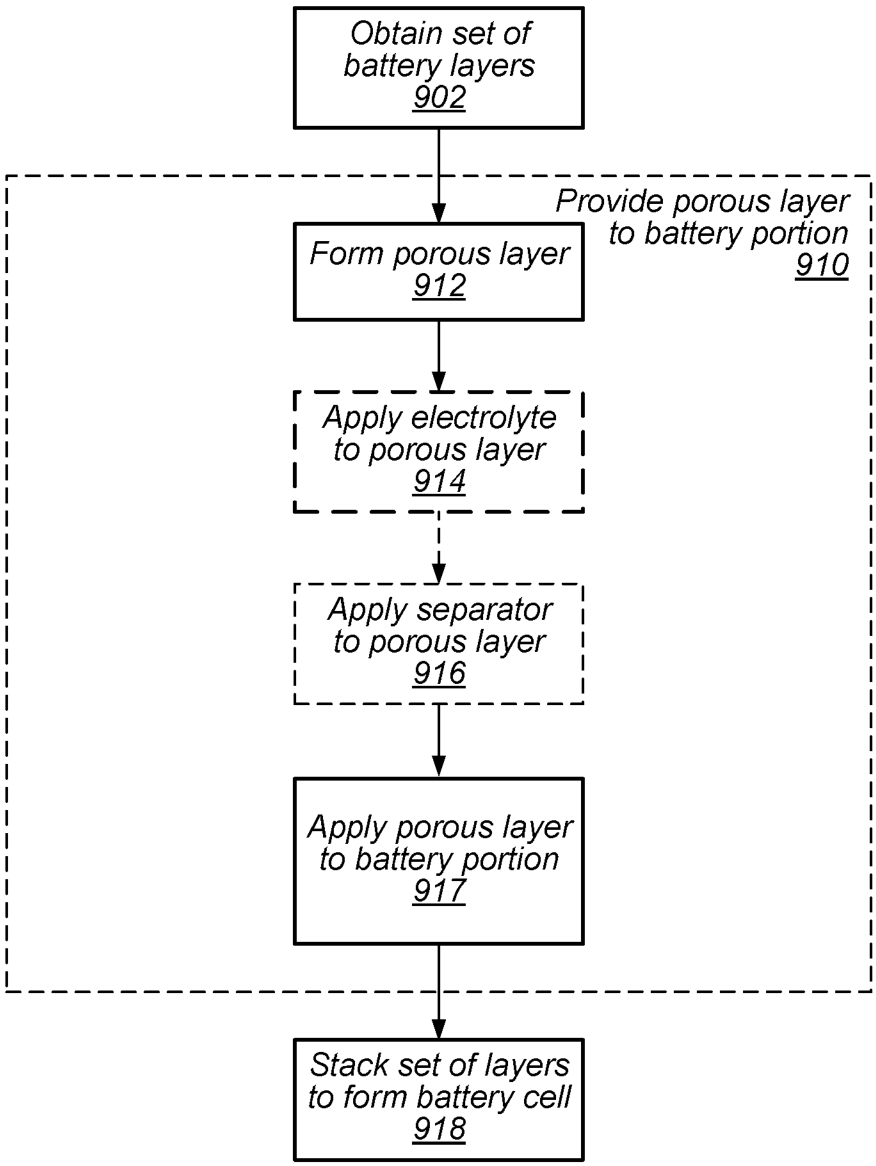

Obtain set of battery layers 902
Provide porous layer to battery portion 910
Form porous layer 912
Apply electrolyte to porous layer 914
Apply separator to porous layer 916
Apply porous layer to battery portion 917
Stack set of layers to form battery cell 918

FIG. 9

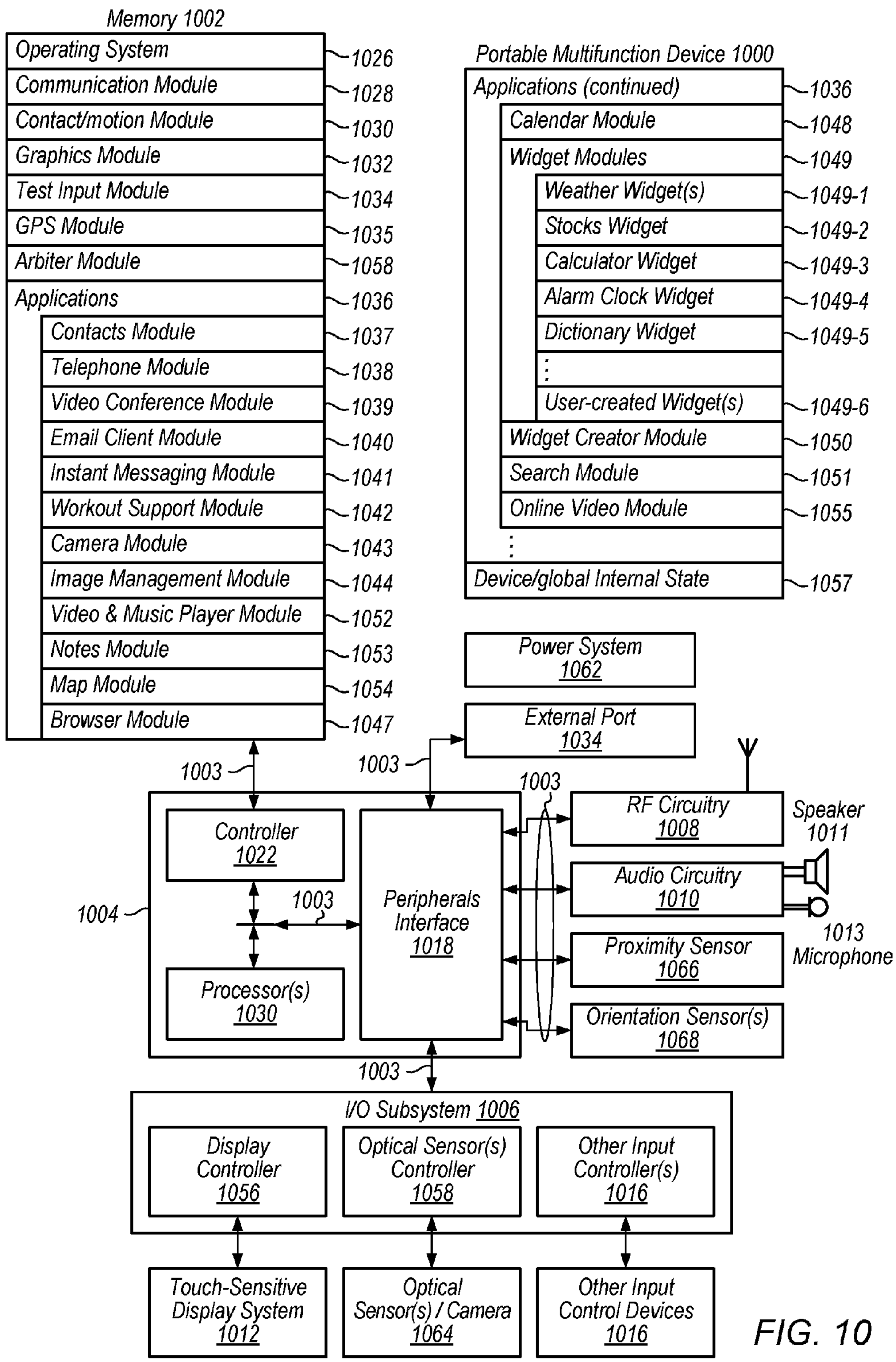

Memory 1002
Operating System
1026
Communication Module
1028
Contact/motion Module
1030
Graphics Module
1032
Test Input Module
1034
GPS Module
1035
Arbiter Module
1058
Applications
1036
Contacts Module
1037
Telephone Module
1038
Video Conference Module
1039
Email Client Module
1040
Instant Messaging Module
1041
Workout Support Module
1042
Camera Module
1043
Image Management Module
1044
Video & Music Player Module
1052
Notes Module
1053
Map Module
1054
Browser Module
1047
Portable Multifunction Device 1000
Applications (continued)
1036
Calendar Module
1048
Widget Modules
1049
Weather Widget(s)
1049-1
Stocks Widget
1049-2
Calculator Widget
1049-3
Alarm Clock Widget
1049-4
Dictionary Widget
1049-5
User-created Widget(s)
1049-6
Widget Creator Module
1050
Search Module
1051
Online Video Module
1055
Device/global Internal State
1057
Power System
1062
External Port
1034
1003
1003
1003
RF Circuitry
1008
Speaker
1011
Audio Circuitry
1010
1013
Microphone
Proximity Sensor
1066
Orientation Sensor(s)
1068
1004
Controller
1022
1003
Peripherals
Interface
1018
Processor(s)
1030
1003
I/O Subsystem 1006
Display
Controller
1056
Optical Sensor(s)
Controller
1058
Other Input
Controller(s)
1016
Touch-Sensitive
Display System
1012
Optical
Sensor(s) / Camera
1064
Other Input
Control Devices
1016

FIG. 10

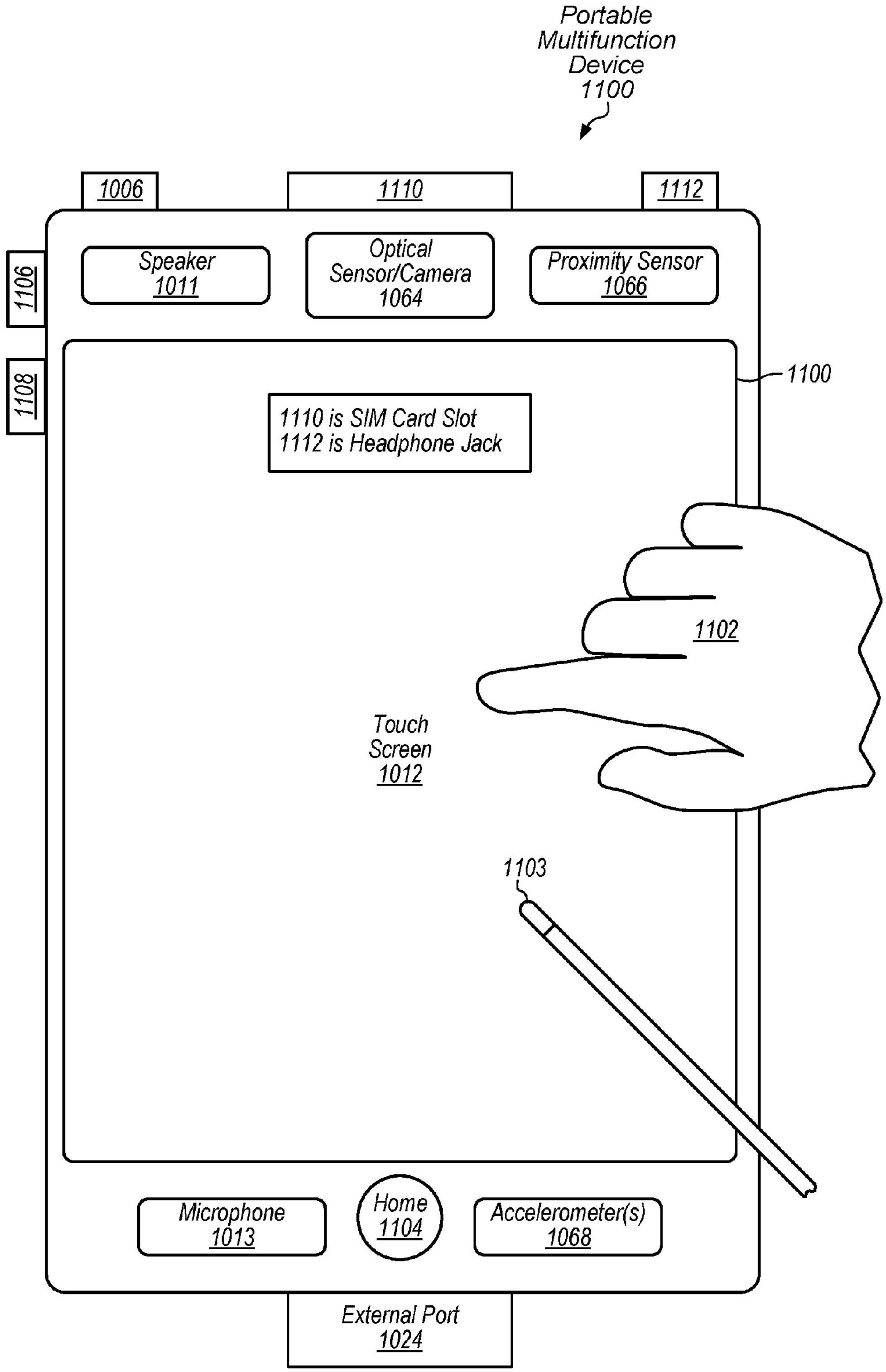
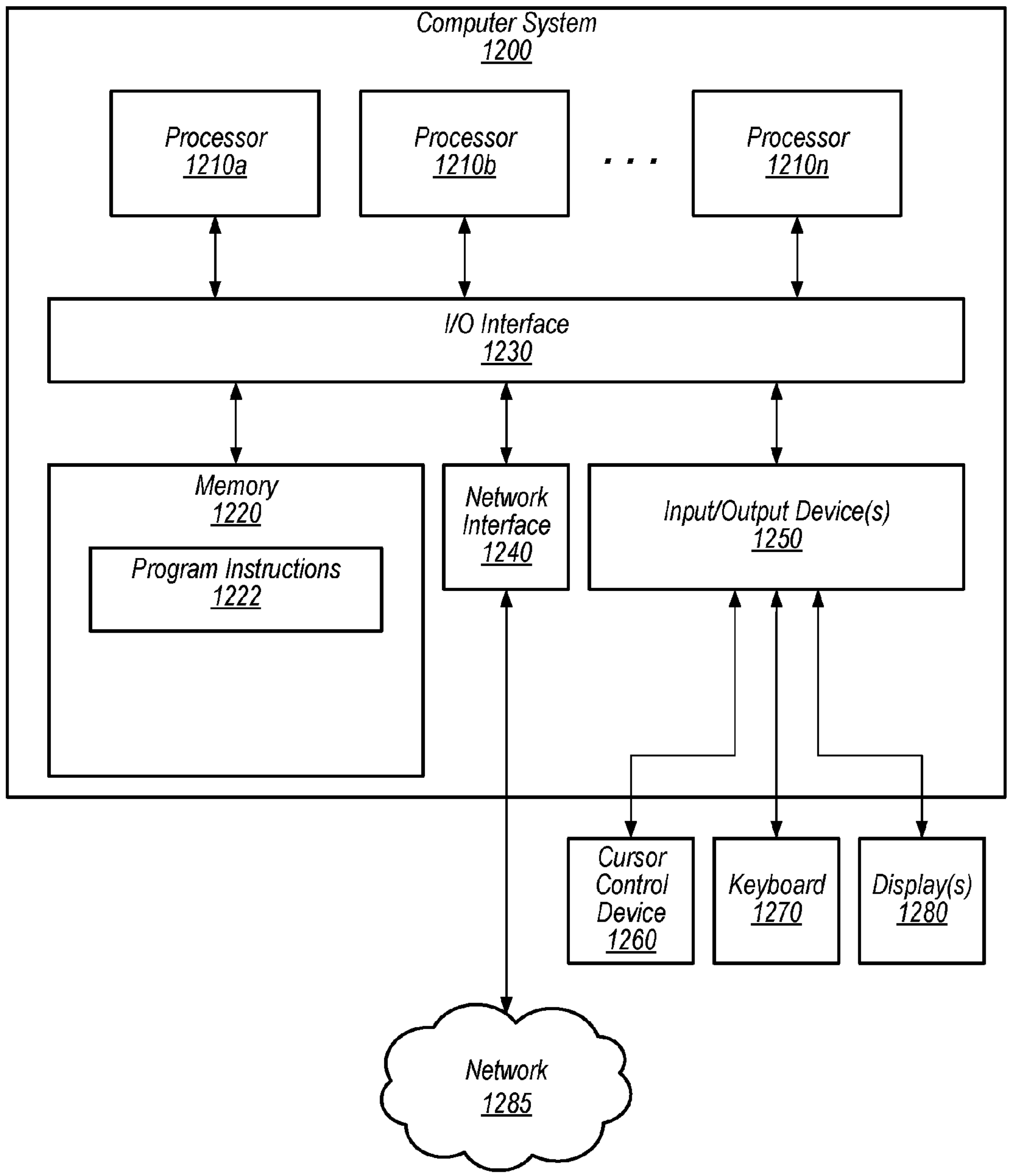

Portable
Multifunction
Device
1100
1006
1110
1112
1106
1108
Speaker
1011
Optical
Sensor/Camera
1064
Proximity Sensor
1066
1100
1110 is SIM Card Slot
1112 is Headphone Jack
1102
Touch
Screen
1012
1103
Microphone
1013
Home
1104
Accelerometer(s)
1068
External Port
1024

FIG. 11



Computer System
1200
Processor
1210a
Processor
1210b
. . .
Processor
1210n
I/O Interface
1230
Memory
1220
Program Instructions
1222
Network
Interface
1240
Input/Output Device(s)
1250
Cursor
Control
Device
1260
Keyboard
1270
Display(s)
1280
Network
1285

FIG. 12

DENDRITE-RESISTANT BATTERY

PRIORITY

[0001] This application claims priority from U.S. Provisional Application No. 62/115,551, entitled "Lithium Dendrite-Resistant Battery" and filed Feb. 12, 2015, the contents of which is incorporated by reference in its entirety herein.

BACKGROUND

[0002] 1. Technical Field

[0003] The disclosed embodiments relate to batteries configured to provide electrical power support to at least some portion of one or more portable electronic devices. More specifically, the disclosed embodiments relate to at least partially resisting dendrite growth between electrodes of a battery.

[0004] 2. Description of the Related Art

[0005] Rechargeable batteries are presently used to provide power to a wide variety of portable electronic devices, including laptop computers, cell phones, PDAs, digital music players and cordless power tools. As these electronic devices become increasingly smaller and more powerful, the batteries that are used to power these devices need to store more energy in a smaller volume.

[0006] A commonly used type of rechargeable battery is a lithium battery, which can include a lithium-ion battery or a lithium-polymer battery. Some lithium batteries may be thin-film batteries with a solid electrolyte. Lithium-ion and lithium-polymer batteries typically contain one or more cells that include a cathode current collector; a cathode comprised of an active material, a separator, an anode current collector; and an anode comprised of an active material. The cathode can comprise a cathode coating, and the anode can comprise an anode coating.

[0007] Lithium batteries conventionally include an anode that is comprised of a graphite material and a cathode that is comprised of a lithium salt material. One technique for increasing the energy capacity (mAh) of a lithium-ion or a lithium-polymer battery involves comprising the anode of a lithium metal material. A lithium battery that includes a lithium metal anode can be configured to have substantially increased energy capacity, relative to a lithium battery of similar size that includes a graphite anode.

[0008] However, charging and discharging such a lithium battery, in some cases, results in the formation of lithium metal structures on the surfaces of the anode. Such structures, referred to herein as lithium dendrites, can "grow" outward from the anode due to repeated charging and discharging cycles of the lithium battery. Some of the lithium dendrites can grow between the anode and the cathode, including growing through various portions of the battery, including one or more battery separators, electrolyte layers, etc. Over time, some lithium dendrites can "grow" in a direction that results in the lithium dendrites approaching the cathode. When a lithium dendrite reaches the cathode, an electrical short circuit (also "short" herein) can be established between the electrodes via the lithium metal comprising the lithium dendrite. Such an electrical short can result in failure of the battery and can further impose a safety risk due to overheating of the battery due to the short circuit, which can further lead to a fire.

SUMMARY OF EMBODIMENTS

[0009] In the descriptions presented below, reference may be made to a lithium battery that comprises one or more lithium cells. However, the apparatuses and methods described may be applicable to other cells and batteries that are not lithium-based. For example, an electrochemical cell of a battery may have an anode on which dendrites can grow, and the apparatuses and methods presented herein may be applied to resist, impede, suppress, and/or prevent one or more dendrites from causing a short circuit between the electrodes of the cell.

[0010] Some embodiments include an apparatus that further includes a battery, such as a lithium battery that is configured to at least partially suppress or resist lithium dendrite growth between electrodes of the battery. The lithium battery, which can include one or more of a lithium ion battery, a lithium polymer battery, a thin film lithium ion battery, etc., typically includes an electrochemically-neutral porous layer configured to permit lithium ion transport across the porous layer and resist or suppress lithium dendrite growth across the porous layer. The electrochemically-neutral porous layer can include a porous anodic aluminum oxide (AAO) layer, which includes pores that may include apertures that extend from a particular surface of the porous layer to an opposite surface of the porous layer, and that are configured to permit lithium ion migration across the AAO layer and to resist lithium dendrite growth across the AAO layer. The electrodes can include a lithium metal anode. The lithium battery can include a battery separator coupled to at least one side of the electrochemically-neutral porous layer, and the battery separator can inhibit lithium ion transport between the electrodes of the lithium battery, based at least in part upon a temperature of the battery separator. The lithium battery can include a liquid electrolyte portion located on at least one side of the electrochemically-neutral porous layer. The lithium battery can include a solid electrolyte portion located on at least one side of the electrochemically-neutral porous layer. The solid electrolyte portion can include a solid electrolyte layer that is applied to at least one side of the electrochemically-neutral porous layer such that the electrochemically-neutral porous layer at least partially structurally supports the solid electrolyte layer, and the electrochemically-neutral porous layer can be applied to at least one side of at least one of the electrodes.

[0011] Some embodiments include a method that includes at least partially fabricating a battery including one or more cells and that can resist dendrite growth between electrodes of a cell of the battery. For example, the battery may be a lithium battery that includes one or more lithium cells, each lithium cell having electrodes including an anode that includes lithium metal. The method includes providing an electrochemically-neutral porous layer between the electrodes. For a lithium battery that includes at least one lithium cell, the electrochemically-neutral porous layer is configured to permit lithium ion transport across the porous layer and to resist lithium dendrite growth from the lithium anode across the porous layer. The electrochemically-neutral porous layer can include a porous anodic aluminum oxide (AAO) layer that comprises a plurality of pores that are configured to permit lithium ion transport across the AAO layer and suppress lithium dendrite growth across the AAO layer.

[0012] Providing the electrochemically-neutral porous layer between the electrodes can include laminating at least the electrochemically-neutral porous layer to at least at least one battery separator, wherein the at least one battery separator is configured to inhibit lithium ion transport between the electrodes of the lithium battery, based at least in part upon a temperature of the at least one battery separator. Providing the electrochemically-neutral porous layer between the electrodes can include applying a solid electrolyte layer to at least one side of the electrochemically-neutral porous layer, such that the electrochemically-neutral porous layer at least partially structurally supports the solid electrolyte layer. Subsequent to applying the solid electrolyte layer, the electrochemically-neutral porous layer may be applied to at least one of the electrodes, on at least one other side of the electrochemically-neutral porous layer, such that the solid electrolyte layer is configured to conduct lithium ions between the electrodes via at least one portion of the electrochemically-neutral porous layer. Applying the solid electrolyte to at least one side of the electrochemically-neutral porous layer can include performing at least one of laminating the solid electrolyte layer to at least one side of the electrochemically-neutral porous layer, depositing the solid electrolyte layer on at least one side of the electrochemically-neutral porous layer, or coating the solid electrolyte layer on at least one side of the electrochemically-neutral porous layer. Providing the electrochemically-neutral porous layer between the electrodes can include laminating the electrochemically-neutral porous layer to at least a portion of the lithium battery. In embodiments, the electrochemically-neutral porous layer can include pores having a maximum pore diameter of 100 nanometers.

[0013] Some embodiments include a portable electronic device that includes at least one functional component that is configured to consume electrical power, and a lithium battery that is configured to provide electrical power support to the at least one functional component. The lithium battery is configured to at least partially suppress lithium dendrite growth between electrodes of the lithium battery, and the lithium battery includes an electrochemically-neutral porous layer that permits lithium ion transport across the porous layer and suppresses lithium metal transport across the porous layer. The electrochemically-neutral porous layer can include a porous anodic aluminum oxide (AAO) layer that comprises a plurality of pores that permit lithium ion transport across the AAO layer and suppress lithium dendrite growth across the AAO layer. The lithium battery can include a solid electrolyte layer that is applied to at least one side of the electrochemically-neutral porous layer, such that the electrochemically-neutral porous layer at least partially structurally supports the solid electrolyte layer. The lithium battery can include a battery separator coupled to at least one side of the electrochemically-neutral porous layer and the battery separator can inhibit lithium ion transport between the electrodes of the lithium battery, based at least in part upon a temperature of the at least one battery separator.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIGS. **1**A-**1**B illustrate lithium batteries that include dendrites growing between electrodes in the respective batteries, according to some embodiments.

[0015] FIG. **2** illustrates a perspective view of an electrochemically-neutral porous layer that is configured to permit lithium ion transport and suppress lithium dendrite growth, according to some embodiments.

[0016] FIG. **3** illustrates an exploded view of a lithium battery that includes an electrochemically-neutral porous layer, which suppresses lithium dendrite growth between the electrodes, according to some embodiments.

[0017] FIGS. **4**A-**4**D illustrate perspective views of lithium batteries, which include an electrochemically-neutral porous layer and at least one battery separator, according to some embodiments.

[0018] FIG. **5** illustrates an exploded view of a lithium battery, which includes multiple layers arranged in a cylindrical coil configuration, according to some embodiments.

[0019] FIG. **6** illustrates a cross-sectional view of a lithium battery, which includes an electrochemically-neutral porous layer, according to some embodiments.

[0020] FIG. **7** illustrates a cross-sectional view of a lithium battery, which includes an electrochemically-neutral porous layer, according to some embodiments.

[0021] FIG. **8** illustrates an exploded view of a lithium battery that includes an electrochemically-neutral porous layer and one or more extended structures coupled to one or more sides of the porous layer, according to some embodiments.

[0022] FIG. **9** illustrates a process for fabricating a lithium battery, according to some embodiments.

[0023] FIG. **10** is a block diagram illustrating an electronic device in accordance with some embodiments.

[0024] FIG. **11** illustrates an exemplary electronic device having a touch screen in accordance with some embodiments.

[0025] FIG. **12** illustrates an exemplary computer system in accordance with some embodiments.

[0026] This specification includes references to "one embodiment" or "an embodiment." The appearances of the phrases "in one embodiment" or "in an embodiment" do not necessarily refer to the same embodiment. Particular features, structures, or characteristics may be combined in any suitable manner consistent with this disclosure.

[0027] "Comprising." This term is open-ended. As used in the appended claims, this term does not foreclose additional structure or steps. Consider a claim that recites: "An apparatus comprising one or more processor units . . . ." Such a claim does not foreclose the apparatus from including additional components (e.g., a network interface unit, graphics circuitry, etc.).

[0028] "Configured To." Various units, circuits, or other components may be described or claimed as "configured to" perform a task or tasks. In such contexts, "configured to" is used to connote structure by indicating that the units/circuits/components include structure (e.g., circuitry) that performs those task or tasks during operation. As such, the unit/circuit/component can be said to be configured to perform the task even when the specified unit/circuit/component is not currently operational (e.g., is not on). The units/circuits/components used with the "configured to" language include hardware—for example, circuits, memory storing program instructions executable to implement the operation, etc. Reciting that a unit/circuit/component is "configured to" perform one or more tasks is expressly intended not to invoke 35 U.S.C. §112, sixth paragraph, for that unit/circuit/component. Additionally, "configured to" can include generic structure (e.g., generic circuitry) that is manipulated by software and/or firmware (e.g., a field programmable gate array (FPGA) or a general-purpose processor executing software) to operate in manner that is capable of performing the task(s) at issue. "Configure to" may also include adapting a manufacturing process (e.g., a semiconductor fabrication facility) to fabricate devices (e.g., integrated circuits) that are adapted to implement or perform one or more tasks.

[0029] "First," "Second," etc. As used herein, these terms are used as labels for nouns that they precede, and do not necessarily imply any type of ordering (e.g., spatial, temporal, logical, etc.). For example, a buffer circuit may be described herein as performing write operations for "first" and "second" values. The terms "first" and "second" do not necessarily imply that the first value must be written before the second value.

[0030] "Based On." As used herein, this term is used to describe one or more factors that affect a determination. This term does not foreclose additional factors that may affect a determination. That is, a determination may be solely based on those factors or based, at least in part, on those factors. Consider the phrase "determine A based on B." While in this case, B is a factor that affects the determination of A, such a phrase does not foreclose the determination of A from also being based on C. In other instances, A may be determined based solely on B.

DETAILED DESCRIPTION OF EMBODIMENTS

[0031] In the descriptions presented below, reference may be made to a lithium battery that comprises one or more lithium cells. However, the apparatuses and methods described may be applicable to other cells and batteries that are not lithium-based. For example, an electrochemical cell of a battery may have an anode on which dendrites can grow, and the apparatuses and methods presented herein may be applied to resist, impede, suppress, and/or prevent one or more dendrites from causing a short circuit between the electrodes of the cell.

[0032] Various embodiments of an apparatus that includes a lithium battery that is configured to resist lithium dendrite growth between electrodes of the lithium battery and methods for at least partially fabricating the apparatus are disclosed.

Lithium Batteries

[0033] FIGS. **1**A-**1**B illustrate lithium batteries that include dendrites growing between electrodes in the respective batteries, according to some embodiments. FIG. **1**A illustrates a battery **100**A, which includes a liquid electrolyte **106**. FIG. **1**B illustrates a battery **100**B, which includes a solid electrolyte **127**.

[0034] Each battery **100**A, **100**B, shown in FIGS. **1**A-**1**B, includes a respective anode **104**, **124**, a respective cathode **112**, **122**, and respective current collectors (**102**, **114**), (**132**, **134**) coupled to distal surfaces of the respective electrodes (**104**, **112**), (**124**, **122**). Battery **100**A further includes a battery separator **108**, which separates the two electrodes **104**, **112**, and an electrolyte **106** in which components **102**, **104**, **108**, **112**, **114** are immersed. In some embodiments, the liquid electrolyte **106** is included in a limited portion of the battery **100**A. For example, the electrolyte **106** can be included in the separator **108**. Battery **100**B includes a solid electrolyte layer **127**, which is located between the electrodes **124**, **122**.

[0035] A lithium battery can include at least one cathode, anode, and electrolyte, which are comprised of various materials. In some embodiments, a lithium battery includes a cathode, which is comprised of one or more various metal oxides. The lithium battery can include electrolyte in one or more various phases. For example, a lithium battery can include a liquid electrolyte, which can include one or more various lithium salts in an organic solvent. In some embodiments, a lithium battery includes an electrolyte layer that includes a molten salt layer. In another example, a lithium battery can include one or more solid electrolyte layers, which can include lithium phosphorous oxynitride ("LiPON") that can be mixed with one or more various binder substances, which can include one or more of polyvinylidene fluoride (PVDF), carboxymethyl cellulose (CMC), one or more Acrylic substances, etc. A solid electrolyte can form a layer in a battery between the electrodes of the battery. In some embodiments, a lithium battery includes at least one liquid electrolyte and at least one solid electrolyte. For example, a lithium battery can include a solid electrolyte layer located between two electrodes, where a liquid electrolyte is included within a porous structure of at least one of the electrodes. In some embodiments, one or more of the electrodes in a lithium battery includes a liquid electrode.

[0036] In some embodiments, battery **100**A includes a separator **108** that comprises an at least partially permeable structure that permits the transport of at least some charge carriers, including lithium ions, between the electrodes **104**, **112**. Such transport can be referred to herein as ionic transport. In some embodiments, the separator **108** includes one or more pores **109** via that one or more charge carriers can pass. In some embodiments, the separator **108** comprises a polymer separator. In some embodiments, the separator **108** is configured to inhibit the electronic transport between the electrodes **104**, **112**, which can include inhibiting charge carrier transport across the separator **108**, based at least in part upon a temperature of the separator **108**. Such a separator can be referred to as a "shutdown separator", because, by inhibiting charge carrier transport based on temperature, the separator is configured to shut down the battery **100**A in response to the battery temperature exceeding a certain temperature. As a result, in addition to keeping the electrodes separated, the separator **108** mitigates safety hazards associated with operation of the battery **100**A. Such a configuration can be associated with the physical structure and composition of the separator. For example, a shutdown separator can be at least partially comprised of one or more polymer materials, including polyethylene, which can melt in response to the local temperature exceeding a threshold, where the melted material coats one or more portions of the separator with a nonconductive layer that inhibits charge carrier transport across the separator, and thus inhibits charge carrier transport between the electrodes.

[0037] In some embodiments, an electrolyte may be used to achieve separation between the electrodes. For example, battery **100**B, which includes electrolyte layer **127** that can include a layer including a solid electrolyte material, does not include a separator between the electrodes **124** and **122**. In some embodiments, battery **100**B includes a liquid electrolyte, which is included within one or more portions of the battery, such that the liquid electrolyte facilitates ionic transport between the solid electrolyte layer **127** and one or more other portions of the battery. For example, where electrolyte layer **127** is a solid electrolyte, cathode **122** can comprise a porous structure in which a liquid electrolyte is included, where the liquid electrolyte can facilitate ionic transport between the solid electrolyte layer **127** and the cathode **122**.

[0038] In some embodiments, the anode (**104**, **124**) of one or more of batteries **100**A-**100**B is comprised of one or more materials that include lithium metal. For example, the anode **104** or **124** can be comprised entirely of lithium metal. As shown in the illustrated embodiments FIG. **1A-100B**, as the battery **100A** or **100B** is repeatedly charged and discharged over time, deposits **120**, **130** of lithium metal can form on a surface of the anode **104**, **124**, and "grow" outward from the anode into the interior structure of the battery **100A**- or **100B**. These deposits, referred to herein as "dendrites", can grow through various portions of the battery. For example, as shown in FIG. **1A**, dendrites **120** extend outwards from a surface of anode **104** and at least partially through the separator **108** that is located between the electrodes **104**, **112** in battery **100A**. In another example, as shown in FIG. **1B**, dendrites **130** extend outwards from a surface of anode **124** and at least partially through the electrolyte layer **127**, which is located between the electrodes **124** and **122** in battery **100B**. Because the dendrites can be at least partially comprised of lithium metal, a dendrite that grows across an entirety of the separation between the electrodes to establish at least electrical contact with the cathode **122** can establish an electrical short circuit (also "short" herein) between the cathode and anode via the dendrite. Such an electrical short can cause failure of the battery and can also produce a safety hazard, including overheating of the battery based on the short, which can lead to a fire.

[0039] In some embodiments, a battery separator in a lithium battery, including a shutdown separator configured to shut down the battery in response to a threshold local temperature, is at least partially permeable by lithium metal such that a lithium dendrite that reaches the separator from the anode can grow through the separator and continue growing towards the cathode. Such permeability can be associated with the pore structure of the separator, where the pores of the separator are sufficiently large so as to permit lithium dendrite growth across the separator. In the illustrated embodiment shown in FIG. **1A**, the dendrites **120** are shown to be growing through the separator **108** via pores **109** in the separator.

[0040] If the dendrites **120**, **130**, shown in FIGS. **1A** and **1B**, continue to grow as a result of repeated charging and discharging of the respective battery **100A**, **100B**, the dendrites can eventually reach the respective cathode **112**, **122** of the respective battery and establish an electrical short between the respective pair of electrodes (**112** and **104**) or (**122** and **124**). In addition, growth of dendrites **120** through the separator **108** of battery **100A** can impart conductivity to the separator **108**, as dendrites **120** comprise electronically conductive lithium material. In embodiments, where the separator **108** is configured to shut down the battery **100A** by forming a nonconductive barrier (e.g., due to heating effects that may be associated with overcharging), dendrite growth through the separator **108** can render the separator conductive and therefore an ineffective shutdown mechanism. As a result, the dendrites **120** can present an additional safety hazard, even if the dendrites do not extend sufficiently between the electrodes to cause a short, by at least partially suppressing the ability of the separator **108** to shut down the battery **100A** in the event of the battery temperature exceeding a threshold temperature.

Electrochemically-Neutral Porous Layer

[0041] FIG. **2** illustrates a perspective view of an electrochemically-neutral porous layer that is configured to permit lithium ion transport and resist lithium dendrite growth, according to some embodiments. The electrochemically-neutral porous layer, also referred to herein interchangeably as a "porous layer," can be included in any of the porous layers included in any of the embodiments included herein.

[0042] In some embodiments, an electrochemically-neutral porous layer is configured to permit at least some charge carriers, including lithium ions, to pass through the layer and is further configured to at least partially suppress or inhibit certain materials, including lithium dendrites, from growing through the layer. As a result, the porous layer is configured to at least partially suppress or inhibit lithium dendrites growing on one side of the porous layer from growing through the porous layer to another side of the porous layer.

[0043] Lithium atoms and lithium ions can have different sizes, i.e., a lithium ion is smaller in radius than the radius of the atom. The size of an atom can be expressed as the "atomic radius" of the atom, and the size of an ion can be expressed as the "ionic radius" of the ion. While some ions, including anions, have an ionic radius that is larger than the atomic radius of the corresponding atom, other ions, including the lithium ion, can have an ionic radius that is smaller than the atomic radius of the corresponding atom. For example, a lithium atom **230** is understood to have an atomic radius **231** of approximately 145-182 picometers. In addition, the radius of lithium in a metallic lattice is further understood to be approximately 152 picometers. In contrast, the ionic radius **221** of the lithium ion **220** (having a +1 charge) is understood to be approximately 68-78 picometers.

[0044] In some embodiments, a porous layer that permits lithium ion transport and resists, inhibits or suppresses lithium dendrite growth includes a structure that further includes a set of pores through which charge carriers, including lithium ions, can pass. The pores have diameters that are sufficiently large to permit lithium ions to pass through the pores and sufficiently small to suppress lithium dendrites from growing through the pores. In some embodiments, the pores have diameters that are sufficiently large to permit lithium ions to pass through the pores, referred to herein as lithium ion transport, and sufficiently small to suppress lithium metal lattices, lithium dendrites, or some combination thereof, etc., from growing through the pore.

[0045] Due at least in part to aggregation of lithium atoms to form dendrites, if pore diameter is sized between approximately 10 and 200 nanometers, the lithium ion **220** can pass through pores **210** but a dendrite, e.g., metallic lattice that may include lithium, may be too large to pass through one or more of the pores **210**; that is, the dendrite may be resisted, impeded, or suppressed from passing through one or more of the pores **210**.

[0046] In some embodiments, an electrochemically-neutral state of the porous layer mitigates reaction hazards associated with the presence of the porous layer in a lithium battery. The electrochemically-neutral porous layer is less prone to chemically interacting with chemical elements of the lithium battery than, e.g., an electrochemically active layer, which could otherwise pose a safety hazard from unexpected and harmful chemical reactions between the layer and one or more chemical substances in the battery.

[0047] In the illustrated embodiment of FIG. **2**, porous layer **200** includes a structure **202** that forms an arrangement of pores **210** that extend through opposite surfaces of the layer **200**. The arrangement of pores **210** can include pores **210** having a substantially uniform diameter **212** between approximately 20 nanometers and approximately 200 nanometers, although pores with diameters as large as 500 nanometers may impede, resist, or otherwise at least partially suppress dendrites from passing through the porous layer **200**. In some embodiments, the porous layer **200** structure **202** is comprised of one or more various materials that result in an electrochemically-neutral dielectric structure **202** and where the porous layer permits lithium ion flow through the pores and resists/inhibits passage of lithium dendritic structures through the pores. In some embodiments, structure **202** comprises anodic aluminum oxide (AAO), and the porous layer **200** can be referred to as a porous AAO layer. AAO is a suitable material from which to form the structure **202** due to its dielectric nature and because it can be formed into a porous layer with pores sized to permit flow of lithium ions through the pores and to resist/inhibit flow of macroscopic lithium structures (e.g., dendrites) through the pores. Other materials may be suitable to form a thin layer (e.g., thickness approximately 50-100 microns) such as the structure **202**, and are dielectric and can be formed into a porous layer. Some or all of the pores of the structure **202** formed from another material may have diameters sized to permit lithium ions to pass through from a first surface of the structure to a second surface of the structure, and impede lithium dendrites from passing through from the first surface of the structure to the second surface of the structure.

[0048] As shown, some or all of the pores **210** have a sufficiently large diameter **212** to permit lithium ions **220** that have a radius **221** to pass through the pores of the porous layer **200**. Conversely, some or all of the pores **210** have a sufficiently small diameter **212** to resist, impede, inhibit, or suppress clusters of atoms (e.g., clusters of lithium atoms **230**, each lithium atom **230** having a radius **231**) such as dendrites or dendrite clusters, from passing through the pores of the porous layer **200**. In some embodiments, the pores **210** are sufficiently small to resist, impede, inhibit, or suppress metal lattices comprising lithium, including lithium dendrites, from growing through the layer via the pores **210**. As a result, lithium dendrite growth through the pores in the layer **200** is resisted, impeded, inhibited, or at least partially suppressed.

[0049] In some embodiments, one or more electrolyte substances are included in the porous layer **200**, where the one or more electrolyte substances facilitate ionic transport between opposite surfaces of the porous layer **200** via one or more of the pores **210**, the structure **202** of the layer **200**, etc. For example, a liquid electrolyte substance can be included within the porous structure of the porous layer **200**, where the liquid electrolyte facilitates ionic transport, including transport of lithium ions **220**, through the porous layer **200**.

[0050] FIG. **3** illustrates an exploded view of a lithium battery that includes an electrochemically-neutral porous layer that suppresses lithium dendrite growth between the electrodes, according to some embodiments. The battery **300** shown in FIG. **3** can include any of the lithium batteries included in any of the embodiments herein, including a battery that includes a liquid electrolyte, a battery that includes a solid electrolyte, a battery that includes at least one liquid electrode, or some combination thereof.

[0051] Battery **300** includes an anode **302**, a cathode **304**, and an electrochemically-neutral porous layer **310** between the two electrolyte regions, where the porous layer **310** includes a set of pores **312** that extend between opposite surfaces of the layer **310** and the opposite surfaces of the layer **310** face into opposite portions of the battery **300**. The illustrated view of the battery **300** is an exploded view to better illustrate features of the battery **300**, e.g., in FIG. **3**, the electrodes (e.g., anode **302** and cathode **304**) are separated from the porous layer **310** by separation distances **306** and **307**, respectively. In some embodiments, one or both of the separation distances **306**, **307** is substantially absent (e.g., of substantially zero length), such that at least one surface of the porous layer **310** contacts a surface of at least one of the electrodes **302**, **304**. In some embodiments, one or more portions of the battery **300** are located between the porous layer **310** and at least one electrode **302**, **304**. In one example, battery **300** can include a separator layer (not shown in FIG. **3**) between the cathode **304** and the porous layer **310**, while porous layer **310** can be in physical contact with a surface of the anode **302**, and a liquid electrolyte can be included in the separator layer (also "separator" herein) between the cathode **304** and the porous layer **310**. In various embodiments, the separator layer may include any of polypropylene (PP), polyethylene (PE), polyimide (PI), polyethylene terephthalate (PET), or a combination thereof. When a separator is present, the porous layer **310** can be of help in the event of thermal failure of the separator (i.e., when the separator is melting). For example, the porous layer **310** may reduce a melting propagation rate of the separator at high temperatures, and may also prevent the anode from directly contacting the cathode as the separator melts.

[0052] In another example, battery **300** can include a solid electrolyte layer (not shown in FIG. **3**) between the porous layer **310** and at least one of the electrodes **302**, **304**, and the porous layer can be in physical contact with at least one other of the electrodes **302**, **304**. In some embodiments, one of the electrolyte regions is absent, and one of the surfaces of the porous layer **310** is in physical contact with at least a portion of a surface of one of the electrodes **302**, **304**.

[0053] In some embodiments, the porous layer **310** permits lithium ion transport across the porous layer **310** and resists, impedes, or at least partially suppresses lithium dendrite growth across the porous layer **310**. As a result, the porous layer **310** facilitates functioning of the battery **300**. That is, the porous layer **310** facilitates the exchange of lithium ions **320** between the electrodes **302**, **304** and the porous layer **310** resists, impedes, or at least partially suppresses the growth of lithium dendrites **330** in the portion of the battery that includes the electrode **302** from which the dendrites originate and may help to prevent the lithium dendrites **330** from establishing one or more electrical shorts between the electrodes **302** and **304**.

[0054] As shown, lithium dendrites **330** are growing from a surface of the anode **302**. In some embodiments, the anode **302** is comprised of one or more materials that include lithium metal. As the battery **300** is repeatedly charged and discharged over time, the lithium dendrites **330** can "grow" outward from the anode **302** to a proximate surface of the porous layer **310**. In some embodiments, separation distance **307** between the anode **302** and the porous layer **310** is minimal, and dendrites protruding from the anode **302** grow directly into contact with the proximate surface of the porous layer **310**.

[0055] As further shown, the porous layer **310**, while permeable to the lithium ions **320**, is resistant to the lithium dendrites **330**. As a result, dendrites **330** that reach the layer **310** from the anode **302** are impeded or resisted from growing through the layer **310**. Thus, the potential for an electrical short caused by a lithium dendrite connecting the electrodes **302**, **304** may be mitigated by porous layer **310**.

[0056] In some embodiments, a lithium battery includes a porous layer that includes pores having a particular selected target pore size, a structure having a particular selected thickness, or both a particular selected pore size and a particular selected thickness. A porous layer can further have a selected material composition. The target pore diameter can be predetermined, and a particular porous layer material that includes pores having the predetermined target pore diameter can be selected and utilized to form the layer **310** included in the battery.

[0057] A predetermined pore diameter of a porous layer material configured to at least partially suppress lithium dendrite growth can include a range of pore diameters. In some embodiments, a porous AAO layer that is included in the lithium battery and at least partially suppresses lithium metal growth (or dendrite growth of other metals or metal alloys, e.g., due to contamination of the anode). includes pores having a target pore diameter of 500 nanometers In some embodiments, a porous AAO layer that is included in the lithium battery and at least partially suppresses lithium metal growth includes pores having a target pore diameter of 100 nanometers. In some embodiments, a porous AAO layer that is included in the lithium battery and at least partially suppresses lithium metal growth includes pores having a target pore diameter of 20 nanometers.

[0058] A predetermined porous layer thickness of a porous layer material that is configured to at least partially suppress lithium dendrite growth can include a range of thicknesses, e.g., approximately 2 μm-20 μm. In some embodiments, a porous AAO layer that is included in the lithium battery and at least partially suppresses lithium metal growth includes a structure having a thickness of approximately 50 micrometers. In some embodiments, a porous AAO layer that is included in the lithium battery and at least partially suppresses lithium metal growth includes a structure having a thickness of approximately 15 micrometers. In some embodiments, a porous AAO layer that is included in the lithium battery and at least partially suppresses lithium metal growth includes a structure having a thickness of approximately 1 micrometer.

[0059] In some embodiments, one or more electrolyte substances included in one or more portions of the battery **300** facilitate ionic transport through the porous layer **310**. Such electrolyte substances can include one or more liquid electrolyte substances. For example, a liquid electrolyte substance can be included within the porous layer **310**, where the liquid electrolyte may facilitate ionic transport, including transport of lithium ions **320**, through the porous layer **310**. In some embodiments, a liquid electrolyte substance is included in one or more other portions of the battery **300**. For example, where one or more of anode **302** and cathode **304** includes a porous structure, a liquid electrolyte can be included within the porous structure of the respective electrode, such that the liquid electrolyte can facilitate ionic transport between the respective electrode and one or more other portions of the battery **300**, including the porous layer **310**.

[0060] FIGS. **4**A-**4**D illustrate perspective views of lithium batteries that include an electrochemically-neutral porous layer and at least one battery separator, according to some embodiments.

[0061] In some embodiments, a lithium battery includes a liquid electrolyte. The liquid electrolyte can be included in one or more particular portions of the battery. For example, the liquid electrolyte can be included in a battery separator, which may be located between the electrodes of the battery. In another example, one or more layers of the battery are immersed in the liquid electrolyte. In some embodiments, a lithium battery includes an electrochemically-neutral porous layer and a battery separator. The porous layer can suppress dendrite growth, and the battery separator can, in addition to separating the electrodes, shut down the battery based at least in part upon a local temperature of the separator. In addition, because the porous layer can resist, impede, or at least partially suppress lithium dendrite growth, the porous layer can resist, impede, or at least partially suppress lithium dendrites from growing through a separator located on an opposite side of the porous layer from the dendrites, so that the dendrites are suppressed from interfering with the shutdown of a battery in the event that a threshold temperature is exceeded for the separator. For example, because a porous layer can resist, impede, or at least partially suppress lithium dendrites from growing through a battery separator, a nonconductive barrier layer, typically formed by the separator when the threshold temperature is exceeded, is not compromised by lithium dendrites spanning through the separator. Additionally, the porous layer may reduce the melting propagation rate of the separator at high temperatures, and may also prevent the anode from directly contacting the cathode as the separator melts.

[0062] FIG. **4**A illustrates a battery that includes a liquid electrolyte, a single battery separator, and a porous layer situated between electrodes of the battery. As shown, battery **400**A includes a cathode **401** a battery separator **404**, a porous layer **406**, an anode **408**, and a liquid electrolyte **402** in which elements **401**-**408** are immersed. In some embodiments (not shown), the liquid electrolyte **402** is included in the separator **404** and is not included in other layers (e.g., cathode **401**, porous layer **406**, anode **408**) of the battery **400**A. The battery separator **404** can be a separator layer. As shown, the battery **400**A is configured to resist, impede, or at least partially suppress lithium dendrites, which may grow from the anode **408**, from passing through the porous layer **406** and reaching separator **404**. As shown, the porous layer **406** can abut a surface of the anode **408** such that the porous layer **406** is in physical contact with at least a portion of a surface of the anode **408**.

[0063] In some embodiments, each layer **404**, **406** comprises a thin film layer, one or more of which can be provided via any known thin film device fabrication techniques. For example, one or more of layers **404**, **406** can be applied to one or more other layers in battery **400**A via one or more of coating, depositing, lamination, etc. In some embodiments, one or more layers provides at least some structural support to another layer, and some layers are combined before the combination of layers is applied to one or more other portions of the battery. For example, the porous layer **406** can be laminated to the separator layer **404**. The combined layers **404**, **406** can then be applied to one or more of the electrodes **401**, **408** via known lamination techniques. In some embodiments, one or more layers are pre-formed and stacked to form the battery **400**A. For example, separator layer **404** and porous layer **406** can be formed via cutting, partitioning, stamping, etc. of one or more larger structures of separator material and porous layer material, respectively, prior to coupling the layers **404**, **406** via one or more various thin film device fabrication techniques.

[0064] FIG. **4**B illustrates a battery that includes a liquid electrolyte, a porous layer, and two battery separators between the electrodes of the battery, where the two battery separators are located on opposite sides of the porous layer.

As shown, battery **400**B includes a cathode **462**, a battery separator **458**, a porous layer **456**, an additional battery separator **454**, an anode **452**, and a liquid electrolyte **460** in which portions **452-462** are immersed. In some embodiments, the liquid electrolyte **460** is included in one or more of the separators **454**, **458** and is not included in other layers of the battery **400**B. One or more of the battery separators **458**, **454** can be a separator layer. As shown, the battery **400**B is configured to resist, impede, or at least partially suppress lithium metal dendrites, which may grow from the anode **452**, from passing through the porous layer **458** and reaching the battery separator **458**. Furthermore, the additional battery separator **454** can provide additional shutdown protection (in addition to shutdown protection to be provided by the battery separator **458**), relative to battery **400**A, in the event of an overheat condition, e.g., where a local temperature exceeds a temperature threshold. As shown, the porous layer **406** can abut a surface of the anode **408**, such that the porous layer is in physical contact with at least a portion of a surface of the anode **408**.

[0065] In some embodiments, a lithium battery includes a solid electrolyte region that comprises a solid electrolyte layer. Such a lithium battery can include a thin film lithium ion battery. In some embodiments, a battery includes a single layer of electrolyte material. The battery can include a porous layer and separator that are arranged in the battery to separate the electrolyte region from the battery electrode from which lithium dendrites can grow, and where at least one battery separator layer is located on a distal side of the porous layer, relative to the battery electrode from which lithium dendrites can grow. As a result, any dendrites originating from the electrode can be resisted, by the porous layer, from growing through both the battery separator and the electrolyte layer.

[0066] In some embodiments, a lithium battery includes a liquid electrode that includes one or more materials in a liquid state. Such a battery can include one or more of an electrolyte layer and separator that are both located between the liquid electrode and another electrode of the battery. The electrolyte layer can include a solid electrolyte layer.

[0067] FIG. **4**C illustrates a battery that includes a single electrolyte layer, a single battery separator, and a porous layer between the electrodes of the battery. At least one of the electrodes can include a liquid electrode. As shown, battery **400**C includes a cathode **411**, an electrolyte layer **412**, a battery separator **414**, a porous layer **416**, and an anode **418**. The electrolyte layer **412** can include a solid electrolyte layer. The battery separator **414** can be a separator layer. As shown, the battery **400**C is configured to resist, impede, or at least partially suppress lithium metal dendrites, which may originate from the anode **418**, from passing through the porous layer **416** and reaching separator **414**. In some embodiments, one or more of electrodes **411**, **418** include a liquid material. As shown, the porous layer **416** can be located adjacent to a surface of the anode **418**. In some embodiments, a surface of the porous layer **416** can abut a surface of the anode **418**.

[0068] In some embodiments, each layer **412**, **414**, **416** comprises a thin film layer, one or more of which can be provided via any known thin film device fabrication techniques. For example, one or more of layers **412**, **414**, **416** can be applied to one or more other layers in battery **400**C via one or more of coating, depositing, lamination, etc. In some embodiments, one or more layers provides at least some structural support to another layer, and some layers are combined before the combination of layers is applied to one or more other portions of the battery. For example, the porous layer **416** can be laminated to the separator layer **414**, and the solid electrolyte layer can be applied to the other surface of the separator layer **414** via one or more of coating, deposition, lamination, etc. The combined layers **412**, **414**, **416** can then be applied to one or more of the electrodes **411**, **418** via known lamination techniques. In some embodiments, one or more layers are pre-formed and stacked to form the battery. For example, separator layer **414** and porous layer **416** can be formed, via cutting, partitioning, stamping, etc. of one or more larger structures of separator material and porous layer material, respectively, prior to coupling the layers **414**, **416** via one or more various thin film device fabrication techniques.

[0069] In some embodiments (not shown), the porous layer **416** is located between the separator **414** and electrolyte layer **412**, such that the electrolyte layer **412** and separator **414** are adjacent to opposite surfaces of the porous layer **416**. In some embodiments (not shown), the porous layer **416** is included within the electrolyte layer **412**, such that one surface of the porous layer **416** is adjacent to or abuts, electrolyte material. In some embodiments (not shown), the porous layer **416** is included within a separator **414**, such that one surface of the porous layer **416** is adjacent to, or abuts, separator material.

[0070] FIG. **4**D illustrates a battery that includes a single electrolyte layer, a porous layer, and two battery separators between the electrodes of the battery, where the two battery separators are located on opposite sides of the porous layer. As shown, battery **400**D includes a cathode **482**, an electrolyte layer **480**, a battery separator **478**, a porous layer **476**, another battery separator **474**, and an anode **408**. The electrolyte layer **480** can include a solid electrolyte layer. One or more of the battery separators **478**, **474** can be a separator layer. As shown, the battery **400**D is configured to resist, impede, or at least partially suppress lithium dendrites, which may grow from the anode **472**, from passing through the porous layer **478** and reaching separator **478**. The additional separator **474** can provide additional shutdown protection, relative to battery **400**C, in the event of an overheat condition where a local temperature (e.g., within battery **400**D) exceeds a temperature threshold. The porous layer may reduce the melting propagation rate of the separator at high temperatures, and may also prevent the anode from directly contacting the cathode as the separator melts. As shown, the porous layer **476** can be located adjacent to, or abutting, a surface of the anode **472**.

[0071] In some embodiments, one or more liquid electrolyte substances are included in one or more portions of the battery, where the one or more liquid electrolyte substances facilitate ionic transport between the one or more portions of the battery and one or more other portions of the battery. For example, in the illustrated embodiment of FIG. **4**C, a liquid electrolyte can be included in porous layer **416** and separator **414**, and electrolyte **412** can be a solid electrolyte layer, where the liquid electrolyte included therein facilitates ionic transport between the anode **418** and the solid electrolyte layer **412**, such that ionic transport between anode **418** and cathode **411** via layers **412-416** is facilitated. In some embodiments, one or more of the cathode and the anode can comprise a porous structure in which a liquid electrolyte substance is included, where the liquid electrolyte substance facilitates ionic transport between the respective electrode and a portion of the battery in physical contact with one or more surfaces of the respective electrode. In another example, in the illustrated embodiment of FIG. 4D, a liquid electrolyte can be included in porous layer **476** and in separators **474** and **478**, and electrolyte **480** can be a solid electrolyte layer, where the liquid electrolyte included therein facilitates ionic transport between the anode **472** and the solid electrolyte layer **480**, such that ionic transport between anode **472** and cathode **482** via layers **474**-**480** is facilitated. In some embodiments, one or more of the cathode and the anode can comprise a porous structure in which a liquid electrolyte substance is included, where the liquid electrolyte substance facilitates ionic transport between the respective electrode and a portion of the battery in physical contact with one or more surfaces of the respective electrode.

[0072] FIG. **5** illustrates a lithium battery that includes multiple layers arranged in a cylindrical coil configuration, according to some embodiments.

[0073] In some embodiments, a lithium battery, which includes an electrochemically-neutral porous layer, includes one or more particular configurations of battery components. For example, the multiple battery components in a battery, including one or more of an anode, cathode, battery separator, porous layer, electrolyte layer, etc., can be separate layers that are rolled into a cylindrical coil configuration. In some embodiments, the anode, cathode, porous layer, and a battery separator can be rolled into a cylindrical configuration of layers and immersed in a liquid electrolyte. As shown in the illustrated embodiment of FIG. **5**, a battery **500** includes a cylindrical coil configuration **502** of layers, which includes battery separator layers **504**, **512**, a porous layer **509**, an anode layer **508**, and a cathode layer **506**. The cylindrical coil configuration **502** of layers can be immersed in a liquid electrolyte **510**. In some embodiments, the battery **500** includes a solid electrolyte layer, which can be rolled, along with the layers **504**, **506**, **508**, **509**, **512** into the cylindrical coil configuration **502**. The porous layer **509** can impede or resist dendrites, which may grow from anode **508**, from piercing the separator **504** and contacting the cathode layer **506**, so as to cause an electrical short circuit. The porous layer **509** can also be of help during thermal failure of the separator **504** (i.e., when the separator **504** is melting). For example, the porous layer **509** may reduce the melting propagation rate of the separator at high temperatures, and may also prevent the anode layer **508** from directly contacting the cathode layer **506** as the separator melts.

[0074] FIG. **6** illustrates a lithium battery that includes an electrochemically-neutral porous layer, according to some embodiments.

[0075] In some embodiments, a lithium battery includes a thin film lithium ion battery that includes solid electrolyte layers. The solid electrolyte in a thin film lithium ion battery can include a mixture of a solid electrolyte and one or more binder materials. For example, an electrolyte layer in the battery can include one or more of LiPON, a PVDF binder, a CMC binder, an Acrylic binder, etc.

[0076] In some embodiments, one or more of the layers in a thin film lithium ion battery can be provided via one or more various known thin film device fabrication techniques. For example, one or more of the layers in a thin film lithium ion battery, including one or more electrode layers, separator layers, electrolyte layers, porous layers, etc. can be provided in a battery via one or more of lamination, coating, deposition, etc. of the respective layers. In some embodiments, a thin film lithium ion battery is fabricated on one or more substrates.

[0077] FIG. **6** shows a thin film lithium ion battery **600**, which includes a stack **601** of thin film layers provided on a substrate **602**. The stack **601** includes an anode current collector **604**, an anode layer **608**, a porous layer **610**, an electrolyte layer **612**, a cathode layer **614**, and a cathode current collector **618**. In some embodiments, the anode layer **608** comprises a lithium metal layer, and the porous layer **610** comprises a porous AAO layer. In some embodiments, the stack **601** further includes an encapsulation layer **620** that can resist permeation into the stack **601**, from an external environment, one or more various environmental elements, which can include one or more of particular matter, precipitation, moisture, etc. In some embodiments, the electrolyte layer **612** includes a solid electrolyte layer.

[0078] As shown, the battery **600** includes a thin film stack **601** of layers. The multiple layers can be applied on the substrate **602**, via a thin film device fabrication technique, to form the battery **600**. Some layers can be pre-formed and stacked to form at least a portion of the stack **601**. Some layers can be formed on other layers that are previously applied to the substrate **602** to form at least a portion of the stack. For example, the porous layer **610** can be pre-formed from a bulk supply of porous layer material and the electrolyte layer **612** can be formed on a surface of the porous layer **610** via one or more of a coating technique, a deposition technique, a lamination technique, etc., to which the combined porous layer **610** and electrolyte layer **612** can be subsequently applied to the anode **608** via, e.g., lamination.

[0079] In some embodiments, one or more layers can provide at least some structural support of one or more other layers of the battery **600**. For example, a solid electrolyte layer (e.g., electrolyte layer **612**) can be at least partially structurally supported by the porous layer **610**.

[0080] In some embodiments, one or more electrolyte substances are included in the porous layer **610**, where the one or more electrolyte substances facilitate ionic transport between opposite surfaces of the porous layer **610** via one or more of the pores included in the porous layer. For example, a liquid electrolyte substance can be included within the porous layer **610**, where the liquid electrolyte facilitates ionic transport, including the transport of lithium ions, through the porous layer **610** between the anode **608** and the electrolyte layer **612**, such that ionic transport between electrodes **608**, **614** via electrolyte layer **612** and porous layer **610** is facilitated. In some embodiments, a liquid electrolyte substance is included in one or more of the electrodes **608**, **614**. For example, where the anode **608** comprises a porous structure, a liquid electrolyte can be included in the anode **608**, and the liquid electrolyte can facilitate ionic transport between the anode **608** and the porous layer **610**.

[0081] It will be understood that the illustrated portions of battery **600** can be arranged in other configurations and include additional components. For example, in another configuration (not shown), battery **600** can include an electrolyte layer between porous layer **610** and anode **608**, such that a surface of the porous layer that is distal from the anode **608** is in physical contact with a surface of the cathode **614**. The cathode **614** can include a porous structure, and a liquid electrolyte can be included in the porous structure of both the porous layer and the cathode **614**. In some embodiments, a liquid electrolyte is included only in the porous layer omitted from either of the electrodes **608**, **614**. In some embodiments, one or more battery separators are located in physical contact with one or more surfaces of the porous layer, and a liquid electrolyte can be included in the separators. For example, in an embodiment where a solid electrolyte layer is included between the porous layer **610** and the anode **608**, a battery separator can be located between the porous layer **610** and the cathode **614**, and a liquid electrolyte can be included in both the battery separator and the porous layer **610**, such that the liquid electrolyte facilitates ionic transport between the solid electrolyte layer and the cathode **614** via the porous layer **610** and the battery separator, to facilitate ionic transport between the anode **608** and the cathode **614** via the solid electrolyte layer, the porous layer **610**, and the battery separator. The porous layer **610** can be of additional help during thermal failure of the battery separator (i.e., when the battery separator is melting). For example, the porous layer **610** may reduce the melting propagation rate of the battery separator at high temperatures, and may also prevent the anode from directly contacting the cathode as the battery separator melts.

[0082] FIG. **7** illustrates a lithium battery that includes an electrochemically-neutral porous layer, according to some embodiments.

[0083] FIG. **7** shows a cross-sectional view of a thin film lithium ion battery **700** that includes a substrate **702** and a stack **701** of layers, which includes a cathode current collector **704**, a cathode layer **708**, a porous layer **710**, an electrolyte layer **712**, an anode layer **714**, an anode current collector **718**, and an encapsulation layer **720** applied on the substrate **702**. In some embodiments, the anode layer **714** comprises a layer of lithium metal, and the porous layer comprises a porous AAO layer. In some embodiments, the electrolyte layer **612** includes a solid electrolyte layer. As shown, in some embodiments the various layers in the battery can be conforming layers, having various thicknesses, which can be applied on a substrate via one or more various known thin film device fabrication techniques.

[0084] In some embodiments, one or more electrolyte substances are included in the porous layer **710**, where the one or more electrolyte substances facilitate ionic transport between opposite surfaces of the porous layer **710** via one or more of the pores included in the porous layer **710**. For example, a liquid electrolyte substance can be included within the porous structure of the porous layer **710**, where the liquid electrolyte facilitates ionic transport, including the transport of lithium ions, through the porous layer **710** between the anode **714** and the electrolyte layer **712**, such that ionic transport between electrodes **708**, **714** via electrolyte layer **712** and porous layer **710** is facilitated.

[0085] It will be understood that the illustrated portions of battery **700** can be arranged in other configurations and include additional components. For example, battery **700** can include an electrolyte layer (not shown) between porous layer **710** and cathode **708**, such that a surface of the porous layer that is distal from the cathode **708** is in physical contact with a surface of the anode **714**. The anode **714** can include a porous structure, and a liquid electrolyte can be included in the porous structure of both the porous layer and the anode **714**. In some embodiments, a liquid electrolyte is included in the porous layer and not either of the electrodes **708**, **714**. In some embodiments, one or more battery separators (not shown) are located in physical contact with one or more surfaces of the porous layer, and a liquid electrolyte can be included in the battery separators. For example, where a solid electrolyte layer is included between the porous layer **710** and the cathode **708**, a battery separator can be located between the porous layer **710** and the anode **714**, and a liquid electrolyte can be included in both the battery separator and the porous layer **710** such that the liquid electrolyte facilitates ionic transport between the electrolyte layer and the anode **714** via the porous layer **710** and the battery separator, facilitating ionic transport between the cathode **708** and the anode **714** via the electrolyte layer, the porous layer **710**, and the battery separator.

[0086] FIG. **8** illustrates an exploded view of a lithium battery that includes an electrochemically-neutral porous layer and one or more extended structures coupled to one or more sides of the porous layer, according to some embodiments. The lithium battery **800** shown in FIG. **8** can be included in any of the embodiments herein.

[0087] In some embodiments, a porous layer is coupled with an extended structure to collectively comprise a support structure that can structurally support at least one layer of solid electrolyte. The support structure can provide a skeleton structure that can support a particular shape of a solid electrolyte layer applied on one or more surfaces of the support structure. The extended structure to which the porous layer is coupled can include one or more various materials. For example, the extended structure can comprise an aluminum foil structure. The extended structure can be coupled to an outer side, also referred to interchangeably herein as an outer "edge", of the porous layer, such that the extended structure extends from the porous layer, establishing a frame of one or more sides of the porous layer.

[0088] In some embodiments, an electrolyte layer is applied to a structure that comprises a porous layer that is coupled to an extended structure, such that the porous layer and extended structure collectively provide structural support to the electrolyte layer, which can include a solid electrolyte layer. In some embodiments, the extended structure provides the structural support. In some embodiments, the electrolyte layer is applied to a limited portion of the combined porous layer and extended structure, so that the electrolyte layer encompasses an entirety of a surface of the porous layer and at least partially encompasses a surface of the extended structure.

[0089] FIG. **8** illustrates a lithium battery **800** that is shown, via exploded view, in three portions: a first portion **801**A, a second portion **801**B, and a stack **810** that is separated from the portions **801**A and **801**B in the illustration by the respective separations **806**A-B. The battery portions **801**A-B can include one or more various battery components, including one or more electrodes, electrolytes, current collectors, some combination thereof, etc.

[0090] It will be understood that, in some embodiments, an illustrated separation between various portions of a battery in an illustrated exploded view of the battery are included for illustration purposes. For example, in the illustrated embodiment shown in FIG. **8**, separation **806**A between battery portion **801**A and stack **810** in the exploded view of battery **800** may be minimal within the battery **800**, such that portions or an entirety of a surface of stack **810** is in physical contact with (e.g., abuts) a surface of battery portion **801**A.

[0091] As shown in FIG. **8**, stack **810** includes a porous layer **812**, which can include any of the porous layer embodiments included herein, and an electrolyte layer **814** that is applied to at least one surface of the porous layer **812**. The electrolyte layer **814** can include a solid electrolyte layer. The porous layer **812** can include an electrolyte that is included within the porous structure of the porous layer; such an electrolyte can include a liquid electrolyte.

[0092] As further shown in FIG. **8**, stack **810** includes one or more extended structures **816**A, **816**B that can be coupled to one or more sides of the porous layer **812** to establish a base structure **811**. Although the illustrated view of the stack **810** illustrates two separate extended structures **816**A, **816**B coupled to opposite sides of the porous layer **812**, it will be understood that, in some embodiments, a single extended structure **816** extends around all sides of the porous layer **812** such that the extended structure **816** establishes a "frame" of the porous layer and the two separate structure portions **816**A, **816**B shown in FIG. **8** are portions of a single continuous extended structure **816**.

[0093] As shown, the electrolyte layer **814** is applied to a surface of the base structure **811**, such that the base structure **811** provides structural support to the electrolyte layer **814**. In some embodiments, the structure portions **816**A, **816**B comprise an aluminum (e.g., aluminum foil) structure that extends from one or more sides of the porous layer **812**, as shown in FIG. **8**. An electrolyte layer **814** may be applied to both the porous layer **812** and at least a portion of the extended structure **816** that comprises the base structure **811**, so that at least a portion of the porous layer **812** and the extended structures **816**A, **816**B comprising the base structure **811** collectively provide structural support to the electrolyte layer **814**. In some embodiments, the extended structures **816**A, **816**B comprise an entirety of the structural support provided to the electrolyte layer **814** by the base structure **811**.

[0094] The porous layer **812**, extended structures **816**A and **816**B, and electrolyte layer **814** can be coupled, as a stack **810**, to one or more of the battery portions **801**A, **801**B such that battery **800** is fabricated. For example, stack **810** can be initially coupled to battery portion **801**A via surfaces of at least the porous layer **812** and subsequently coupled to battery portion **801**B via one or more surfaces of one or more of the electrolyte layer **814**, porous layer **812**, extended structures **816**A and **816**B, or some combination thereof. In some embodiments, the extended structures **816**A, **816**B at least partially restricts an electrolyte included in the porous layer **812**, including a liquid electrolyte, from leaving the porous layer **812** via the sides of the porous layer that are coupled to at least one extended structure **816**A, **816**B.

Battery Fabrication

[0095] Those skilled in the art will appreciate that a number of techniques may be used to fabricate a lithium battery. In some embodiments, a lithium battery that is configured to at least partially resist, impede, or suppress lithium dendrite growth between electrodes in the battery can be at least partially fabricated via various techniques.

[0096] In some embodiments, one or more sets of materials used to form one or more components of the lithium battery are provided to process as material stock. For example, where the battery includes a solid electrolyte layer, the solid electrolyte material can be provided as a powder stock, which can be mixed with one or more selected binders and applied to another formed battery layer, including the porous layer, via one or more various application processes, including coating, deposition, lamination, or some combination thereof. The porous layer can be applied to one or more portions of the battery, including one or more electrodes, via one or more various processes, including coating, depositing, laminating, etc. of the porous layer, and any layers applied to the porous layer, to the one or more battery portions.

[0097] FIG. **9** illustrates a process **900** for fabricating a lithium battery, according to some embodiments. The fabricating can be controlled by one or more computer systems, which are described further below.

[0098] At block **902**, a set of battery components are obtained. Battery components can include one or more battery electrodes, including one or more cathodes, anodes, etc. Battery components can include an electrochemically-neutral porous layer, an electrolyte material, a battery separator, etc. In some embodiments, one or more of the battery components are obtained as a set of material that can be used to form one or more layers of the battery. For example, the electrochemically-neutral porous layer can be obtained as a roll of layer material that can be cut, segmented, partitioned, etc. to form an individual layer for an individual battery. In another example, starting material of an electrolyte layer, including LiPON, one or more additional materials, including PVDF binders, CMC binders, acrylic binders, etc., can be obtained as a mass of material stock that can be applied to one or more surfaces, as described further below, to form one or more electrolyte layers. In some embodiments, obtaining the battery components includes obtaining an anode material that is used to form one or more anodes of the battery, where the anode material comprises lithium metal.

[0099] In some embodiments, obtaining a set of battery components includes obtaining an electrochemically-neutral porous layer material that includes a particular material composition, a pore structure of pores having a particular selected pore size and a particular selected layer material thickness. For example, the electrochemically-neutral porous layer material can include an anodic aluminum oxide layer material that includes pores having an approximate pore diameter that does not exceed approximately 100 nanometers, and a having a thickness of 1-50 micrometers. In some embodiments, the pores in the layer material include pores having an approximate pore diameter between 10 nanometers and 100 nanometers, and in other embodiments the pores in the layer material may have an approximate port diameter between 20 nanometers and 500 nanometers.

[0100] At block **910**, the electrochemically-neutral porous layer is provided between the electrodes of the battery. Such providing can include applying the porous layer to a portion of the battery that includes a single electrode, and subsequently applying the other electrode to the portion that includes the applied porous layer.

[0101] As shown by blocks **912**, **914**, **916**, and **917**, the providing can include various elements. As shown at block **912**, the electrochemically-neutral porous layer can be formed from the obtained layer material. Such layer formation can include partitioning, cutting, etc. an obtained set of layer material stock into an individual layer. In some embodiments, forming the layer includes applying at least some of the layer material to a substrate, carrier film, etc. Such applying of material to form a layer can include any known method for forming a layer from a material stock, including atomic layer deposition, coating of materials, lamination of materials, etc.

[0102] At block **914**, where the lithium battery being fabricated is to comprise at least one solid electrolyte layer, at least one solid electrolyte layer material can be applied to at least one surface of the porous layer, such that at least one solid electrolyte layer is formed on the at least one surface of the porous layer. The solid electrolyte material can include any known solid electrolytes, including LiPON, a mixture that includes one or more of PVDF binders, CMC binders, acrylic binders, etc. Applying solid electrolyte layer material to a surface of the porous layer can include one or more of coating the material over at least a particular selected portion of the porous layer to form the solid electrolyte layer, depositing the material over at least a particular selected portion of the porous layer to form the solid electrolyte layer, laminating the material on at least a particular selected portion of the porous layer to form the solid electrolyte layer, etc.

[0103] Applying the solid electrolyte material to a particular selected portion of the porous layer can result in forming a solid electrolyte layer that extends over a selected particular portion of the porous layer in a particular selected pattern. In some embodiments, applying the solid electrolyte material to the porous layer results in the formation of a solid electrolyte layer that is at least partially structurally supported by the porous layer. For example, the porous layer material can provide a structural skeleton structure that supports a particular shape of the solid electrolyte layer applied on one or more surfaces of the porous layer. In some embodiments, one or more solid electrolyte layers are applied on multiple surfaces of the porous layer, such that multiple separate solid electrolyte layers are formed.

[0104] At block **916**, one or more battery separator materials are applied to one or more sides of the porous layer, such that one or more battery separator layers are formed. Applying battery separator material to a side of the porous layer can include one or more of coating the material over at least a particular selected portion of the porous layer to form the solid electrolyte layer, depositing the material over at least a particular selected portion of the porous layer to form the solid electrolyte layer, laminating the material on at least a particular selected portion of the porous layer to form the solid electrolyte layer, etc.

[0105] At block **917**, the porous layer is applied to a portion of the lithium battery. The portion of the lithium battery can include one or more electrodes, such that applying the porous layer includes applying at least a portion of the porous layer directly to at least one surface of at least one electrode.

[0106] At block **914**, a solid electrolyte layer is applied to at least one surface of the porous layer, and applying the porous layer to a battery portion includes applying the combined porous layer and solid electrolyte layer to the battery portion, subsequent to forming the solid electrolyte layer on one or more surfaces of the porous layer. Applying the porous layer to the battery portion can include applying a surface of the porous layer that is distal from the surface on which the solid electrolyte layer is formed, to the battery portion, such that the porous layer is located between the solid electrolyte layer and the battery portion.

[0107] At block **916**, in some embodiments, the battery separator is applied to at least one surface of the porous layer. At block **917**, the method includes applying the porous layer to a battery portion, which includes applying the combined porous layer and battery separator to the battery portion subsequent to applying the battery separator on one or more surfaces of the porous layer. Applying the porous layer to the battery portion can include applying a surface of the porous layer that is distal from the surface on which the battery separator is applied, to the battery portion, such that the porous layer is located between the battery separator and the battery portion.

[0108] Applying the porous layer to the battery portion can include one or more of coating the porous layer over at least a particular selected portion of the battery portion, depositing the porous layer over at least a particular selected portion of the battery portion, laminating the porous layer over at least a particular selected portion of the battery portion, etc.

[0109] At block **918**, a remainder of the battery components is applied to the battery portion, such that the battery is fabricated. The application can include stacking multiple separate layers over the porous layer that is applied to the battery portion. In some embodiments, the application includes applying an electrode, current collector, thin film layer, encapsulation layer, or some combination thereof over the applied porous layer to complete the fabrication of the battery.

[0110] In some embodiments, fabricating the lithium battery includes applying a liquid electrolyte to one or more portions of the battery. For example, one or more of forming the porous layer (block **912**), applying the separator to the porous layer **916**, applying the porous layer to a battery portion (block **917**), and applying a remainder of battery components to the battery portion (block **912**) can include applying a liquid electrolyte substance to one or more of the porous layer, the battery separator, one or more of the electrodes, or some combination thereof.

Electronic Device Examples

[0111] Embodiments of electronic devices in which embodiments of batteries as described herein may be used are described.

[0112] Attention is now directed toward embodiments of portable devices with cameras. FIG. **10** illustrates device **1000**, which may be powered by one or more of the batteries described above with reference to FIGS. **1-8**.

[0113] Device **1000** is a multifunction device (e.g., a computing device) that may include memory **1002** (that may include one or more computer readable storage mediums), memory controller **1022**, one or more processing units (CPU's) **1020**, peripherals interface **1018**, RF circuitry **1008**, audio circuitry **1010**, speaker **1011**, touch-sensitive display system **1012**, microphone **1013**, input/output (I/O) subsystem **1006**, other input or control devices **1016**, and external port **1024**. Device **1000** may include one or more optical sensors **1064**. These components may communicate over one or more communication buses or signal lines **1003**.

[0114] Memory **1002** may include high-speed random access memory and may also include non-volatile memory, such as one or more magnetic disk storage devices, flash memory devices, or other non-volatile solid-state memory devices. Access to memory **1002** by other components of device **1000**, such as CPU **1020** and the peripherals interface **1018**, may be controlled by memory controller **1022**.

[0115] Peripherals interface **1018** can be used to couple input and output peripherals of the device to CPU **1020** and memory **1002**. The one or more processors **1020** run or execute various software programs and/or sets of instructions stored in memory **1002** to perform various functions for device **1000** and to process data.

[0116] In some embodiments, peripherals interface **1018**, CPU **1020**, and memory controller **1022** may be implemented on a single chip, such as chip **1004**. In some other embodiments, they may be implemented on separate chips.

[0117] RF (radio frequency) circuitry **1008** receives and sends RF signals, also called electromagnetic signals. RF circuitry **1008** converts electrical signals to/from electromagnetic signals and communicates with communications networks and other communications devices via the electromagnetic signals.

[0118] Audio circuitry **1010**, speaker **1011**, and microphone **1013** provide an audio interface between a user and device **1000**. Audio circuitry **1010**, which can include one or more audio communication interfaces, receives audio data from peripherals interface **1018**, converts the audio data to an electrical signal, and transmits the electrical signal to speaker **1011**. Speaker **1011** converts the electrical signal to human-audible sound waves. Audio circuitry **1010** also receives electrical signals converted by microphone **1013** from sound waves. Audio circuitry **1010** converts the electrical signal to audio data and transmits the audio data to peripherals interface **1018** for processing. Audio data may be retrieved from and/or transmitted to memory **102** and/or RF circuitry **1008** by peripherals interface **1018**. In some embodiments, audio circuitry **1010** also includes a headset jack (e.g., **1012**, FIG. **10**). The headset jack provides an interface between audio circuitry **1010** and removable audio input/output peripherals, such as output-only headphones or a headset with both output (e.g., a headphone for one or both ears) and input (e.g., a microphone).

[0119] I/O subsystem **1006** couples input/output peripherals on device **1000**, such as touch screen **1012** and other input control devices **1016**, to peripherals interface **1018**. I/O subsystem **1006** may include display controller **1056** and one or more input controllers **1060** for other input or control devices. The one or more input controllers **160** receive/send electrical signals from/to other input or control devices **1016**. The other input control devices **1016** may include physical buttons (e.g., push buttons, rocker buttons, etc.), dials, slider switches, joysticks, click wheels, and so forth. In some alternative embodiments, input controller(s) **1060** may be coupled to any (or none) of the following: a keyboard, infrared port, USB port, and a pointer device such as a mouse. The one or more buttons (e.g., **1008**, FIG. **10**) may include an up/down button for volume control of speaker **1011** and/or microphone **1013**. The one or more buttons may include a push button (e.g., **1006**, FIG. **10**).

[0120] Touch-sensitive display **1012** provides an input interface and an output interface between the device and a user. Display controller **1056** receives and/or sends electrical signals from/to touch screen **1012**. Touch screen **1012** displays visual output to the user. The visual output may include graphics, text, icons, video, and any combination thereof (collectively termed "graphics"). In some embodiments, some or all of the visual output may correspond to user-interface objects.

[0121] Touch screen **1012** has a touch-sensitive surface, sensor or set of sensors that accepts input from the user based on haptic and/or tactile contact. Touch screen **1012** and display controller **1056** (along with any associated modules and/or sets of instructions in memory **1002**) detect contact (and any movement or breaking of the contact) on touch screen **1012** and converts the detected contact into interaction with user-interface objects (e.g., one or more soft keys, icons, web pages or images) that are displayed on touch screen **1012**. In an example embodiment, a point of contact between touch screen **1012** and the user corresponds to a finger of the user.

[0122] Device **1000** also includes power system **1062** for powering the various components. Power system **1062** may include a power management system, one or more power sources (e.g., battery, alternating current (AC)), a recharging system, a power failure detection circuit, a power converter or inverter, a power status indicator (e.g., a light-emitting diode (LED)) and any other components associated with the generation, management and distribution of power in portable devices.

[0123] Device **1000** may also include one or more optical sensors or cameras **1064**. FIG. **10** shows an optical sensor coupled to optical sensor controller **1058** in I/O subsystem **1006**. Optical sensor **1064** may include charge-coupled device (CCD) or complementary metal-oxide semiconductor (CMOS) phototransistors. Optical sensor **1064** receives light from the environment, projected through one or more lens, and converts the light to data representing an image. In conjunction with imaging module **1043** (also called a camera module), optical sensor **1064** may capture still images or video. In some embodiments, an optical sensor is located on the back of device **1000**, opposite touch screen display **1012** on the front of the device, so that the touch screen display may be used as a viewfinder for still and/or video image acquisition. In some embodiments, another optical sensor is located on the front of the device so that the user's image may be obtained for videoconferencing while the user views the other videoconference participants on the touch screen display.

[0124] Device **1000** may also include one or more proximity sensors **1066**. FIG. **10** shows proximity sensor **1066** coupled to peripherals interface **1018**. Alternatively, proximity sensor **1066** may be coupled to input controller **1060** in I/O subsystem **1006**. In some embodiments, the proximity sensor turns off and disables touch screen **1012** when the multifunction device is placed near the user's ear (e.g., when the user is making a phone call).

[0125] Device **1000** includes one or more orientation sensors **1068**. In some embodiments, the one or more orientation sensors include one or more accelerometers (e.g., one or more linear accelerometers and/or one or more rotational accelerometers).

[0126] In some embodiments, the software components stored in memory **1002** include operating system **1026**, communication module (or set of instructions) **1028**, contact/motion module (or set of instructions) **1030**, graphics module (or set of instructions) **1032**, text input module (or set of instructions) **1034**, Global Positioning System (GPS) module (or set of instructions) **1035**, arbiter module **1057** and applications (or sets of instructions) **1036**. Furthermore, in some embodiments memory **1002** stores device/global internal state **1057**. Device/global internal state **1057** includes one or more of: active application state, indicating which applications, if any, are currently active; display state, indicating what applications, views or other information occupy various regions of touch screen display **1012**; sensor state, including information obtained from the device's various sensors and input control devices **1016**; and location information concerning the device's location and/or attitude.

[0127] Communication module **1028** facilitates communication with other devices over one or more external ports **1024** and also includes various software components for handling data received by RF circuitry **1008** and/or external port **1024**. External port **1024** (e.g., Universal Serial Bus (USB), FIREWIRE, etc.) is adapted for coupling directly to other devices or indirectly over a network (e.g., the Internet, wireless LAN, etc.).

[0128] Contact/motion module **1030** may detect contact with touch screen **1012** (in conjunction with display controller **1056**) and other touch sensitive devices (e.g., a touchpad or physical click wheel). Contact/motion module **1030** includes various software components for performing various operations related to detection of contact, such as determining if contact has occurred (e.g., detecting a finger-down event), determining if there is movement of the contact and tracking the movement across the touch-sensitive surface (e.g., detecting one or more finger-dragging events), and determining if the contact has ceased (e.g., detecting a finger-up event or a break in contact). Contact/motion module **1030** receives contact data from the touch-sensitive surface. Determining movement of the point of contact, which is represented by a series of contact data, may include determining speed (magnitude), velocity (magnitude and direction), and/or an acceleration (a change in magnitude and/or direction) of the point of contact. These operations may be applied to single contacts (e.g., one finger contacts) or to multiple simultaneous contacts (e.g., "multitouch"/multiple finger contacts). In some embodiments, contact/motion module **1030** and display controller **1056** detect contact on a touchpad.

[0129] Graphics module **1032** includes various known software components for rendering and displaying graphics on touch screen **1012** or other display, including components for changing the intensity of graphics that are displayed. In some embodiments, graphics module **1032** stores data representing graphics to be used. Each graphic may be assigned a corresponding code. Graphics module **1032** receives, from applications etc., one or more codes specifying graphics to be displayed along with, if necessary, coordinate data and other graphic property data, and then generates screen image data to output to display controller **1056**.

[0130] Text input module **1034**, which may be a component of graphics module **1032**, provides soft keyboards for entering text in various applications (e.g., contacts **1037**, e-mail **1040**, IM **141**, browser **1047**, and any other application that needs text input).

[0131] GPS module **1035** determines the location of the device and provides this information for use in various applications (e.g., to telephone **1038** for use in location-based dialing, to camera module **1043** as picture/video metadata, and to applications that provide location-based services such as weather widgets, local yellow page widgets, and map/navigation widgets).

[0132] Applications **1036** may include the following modules (or sets of instructions), or a subset or superset thereof:

- **[0133]** contacts module **1037** (sometimes called an address book or contact list);
- **[0134]** telephone module **1038**;
- **[0135]** video conferencing module **1039**;
- **[0136]** e-mail client module **1040**;
- **[0137]** instant messaging (IM) module **1041**;
- **[0138]** workout support module **1042**;
- **[0139]** camera module **1043** for still and/or video images;
- **[0140]** image management module **1044**;
- **[0141]** browser module **1047**;
- **[0142]** calendar module **1048**;
- **[0143]** widget modules **1049**, which may include one or more of: weather widget **1049-1**, stocks widget **1049-2**, calculator widget **1049-3**, alarm clock widget **1049-4**, dictionary widget **1049-5**, and other widgets obtained by the user, as well as user-created widgets **1049-6**;
- **[0144]** widget creator module **1050** for making user-created widgets **1049-6**;
- **[0145]** search module **1051**;
- **[0146]** video and music player module **1052**, which may be made up of a video player
- **[0147]** module and a music player module;
- **[0148]** notes module **1053**;
- **[0149]** map module **1054**; and/or
- **[0150]** online video module **1055**.

[0151] Examples of other applications **1036** that may be stored in memory **1002** include other word processing applications, other image editing applications, drawing applications, presentation applications, JAVA-enabled applications, encryption, digital rights management, voice recognition, and voice replication.

[0152] In conjunction with touch screen **1012**, display controller **1056**, contact module **1030**, graphics module **1032**, and text input module **1034**, contacts module **1037** may be used to manage an address book or contact list (e.g., stored in application internal state **1092** of contacts module **1037** in memory **1002**), including: adding name(s) to the address book; deleting name(s) from the address book; associating telephone number(s), e-mail address(es), physical address (es) or other information with a name; associating an image with a name; categorizing and sorting names; providing telephone numbers or e-mail addresses to initiate and/or facilitate communications by telephone **1038**, video conference **1039**, e-mail **1040**, or IM **1041**; and so forth.

[0153] In conjunction with RF circuitry **1008**, audio circuitry **1010**, speaker **1011**, microphone **1013**, touch screen **1012**, display controller **1056**, contact module **1030**, graphics module **1032**, and text input module **1034**, telephone module **1038** may be used to enter a sequence of characters corresponding to a telephone number, access one or more telephone numbers in address book **1037**, modify a telephone number that has been entered, dial a respective telephone number, conduct a conversation and disconnect or hang up when the conversation is completed. As noted above, the wireless communication may use any of a variety of communications standards, protocols and technologies.

[0154] In conjunction with RF circuitry **1008**, audio circuitry **1010**, speaker **1011**, microphone **1013**, touch screen **1012**, display controller **1056**, optical sensor **1064**, optical sensor controller **1058**, contact module **1030**, graphics module **1032**, text input module **1034**, contact list **1037**, and telephone module **1038**, videoconferencing module **109** includes executable instructions to initiate, conduct, and terminate a video conference between a user and one or more other participants in accordance with user instructions.

[0155] In conjunction with RF circuitry **1008**, touch screen **1012**, display controller **1056**, contact module **1030**, graphics module **1032**, and text input module **1034**, e-mail client module **1040** includes executable instructions to create, send, receive, and manage e-mail in response to user instructions. In conjunction with image management module **1044**, e-mail client module **1040** makes it very easy to create and send e-mails with still or video images taken with camera module **1043**.

[0156] In conjunction with RF circuitry **1008**, touch screen **1012**, display controller **1056**, contact module **1030**, graphics module **1032**, and text input module **1034**, the instant messaging module **1041** includes executable instructions to enter a sequence of characters corresponding to an instant message, to modify previously entered characters, to transmit a respective instant message (for example, using a Short Message Service (SMS) or Multimedia Message Service (MMS) protocol for telephony-based instant messages or using XIVIPP, SIMPLE, or IMPS for Internet-based instant messages), to receive instant messages and to view received instant messages. In some embodiments, transmitted and/or received instant messages may include graphics, photos, audio files, video files and/or other attachments as are supported in a MMS and/or an Enhanced Messaging Service (EMS). As used herein, "instant messaging" refers to both telephony-based messages (e.g., messages sent using SMS or MMS) and Internet-based messages (e.g., messages sent using XMPP, SIMPLE, or IMPS).

[0157] In conjunction with RF circuitry **1008**, touch screen **1012**, display controller **1056**, contact module **1030**, graphics module **1032**, text input module **1034**, GPS module **1035**, map module **1054**, and music player module **1046**, workout support module **1042** includes executable instructions to create workouts (e.g., with time, distance, and/or calorie burning goals); communicate with workout sensors (sports devices); receive workout sensor data; calibrate sensors used to monitor a workout; select and play music for a workout; and display, store and transmit workout data.

[0158] In conjunction with touch screen **1012**, display controller **1056**, optical sensor(s) **1064**, optical sensor controller **1058**, contact module **1030**, graphics module **1032**, and image management module **1044**, camera module **1043** includes executable instructions to capture still images or video (including a video stream) and store them into memory **1002**, modify characteristics of a still image or video, or delete a still image or video from memory **1002**.

[0159] In conjunction with touch screen **1012**, display controller **1056**, contact module **1030**, graphics module **1032**, text input module **1034**, and camera module **1043**, image management module **1044** includes executable instructions to arrange, modify (e.g., edit), or otherwise manipulate, label, delete, present (e.g., in a digital slide show or album), and store still and/or video images.

[0160] In conjunction with RF circuitry **1008**, touch screen **1012**, display system controller **1056**, contact module **1030**, graphics module **1032**, and text input module **1034**, browser module **1047** includes executable instructions to browse the Internet in accordance with user instructions, including searching, linking to, receiving, and displaying web pages or portions thereof, as well as attachments and other files linked to web pages.

[0161] In conjunction with RF circuitry **1008**, touch screen **1012**, display system controller **1056**, contact module **1030**, graphics module **1032**, text input module **1034**, e-mail client module **1040**, and browser module **1047**, calendar module **1048** includes executable instructions to create, display, modify, and store calendars and data associated with calendars (e.g., calendar entries, to do lists, etc.) in accordance with user instructions.

[0162] In conjunction with RF circuitry **1008**, touch screen **1012**, display system controller **1056**, contact module **1030**, graphics module **1032**, text input module **1034**, and browser module **1047**, widget modules **1049** are mini-applications that may be downloaded and used by a user (e.g., weather widget **1049-1**, stocks widget **1049-2**, calculator widget **10493**, alarm clock widget **1049-4**, and dictionary widget **1049-5**) or created by the user (e.g., user-created widget **1049-6**). In some embodiments, a widget includes an HTML (Hypertext Markup Language) file, a CSS (Cascading Style Sheets) file, and a JavaScript file. In some embodiments, a widget includes an XML (Extensible Markup Language) file and a JavaScript file (e.g., Yahoo! Widgets).

[0163] In conjunction with RF circuitry **1008**, touch screen **1012**, display system controller **1056**, contact module **1030**, graphics module **1032**, text input module **1034**, and browser module **1047**, the widget creator module **1050** may be used by a user to create widgets (e.g., turning a user-specified portion of a web page into a widget).

[0164] In conjunction with touch screen **1012**, display system controller **1056**, contact module **1030**, graphics module **1032**, and text input module **1034**, search module **1051** includes executable instructions to search for text, music, sound, image, video, and/or other files in memory **1002** that match one or more search criteria (e.g., one or more user-specified search terms) in accordance with user instructions.

[0165] In conjunction with touch screen **1012**, display system controller **1056**, contact module **1030**, graphics module **1032**, audio circuitry **1010**, speaker **1011**, RF circuitry **1008**, and browser module **1047**, video and music player module **1052** includes executable instructions that allow the user to download and play back recorded music and other sound files stored in one or more file formats, such as MP3 or AAC files, and executable instructions to display, present or otherwise play back videos (e.g., on touch screen **1012** or on an external, connected display via external port **1024**). In some embodiments, device **1000** may include the functionality of an MP3 player.

[0166] In conjunction with touch screen **1012**, display controller **1056**, contact module **1030**, graphics module **1032**, and text input module **1034**, notes module **1053** includes executable instructions to create and manage notes, to do lists, and the like in accordance with user instructions.

[0167] In conjunction with RF circuitry **1008**, touch screen **1012**, display system controller **1056**, contact module **1030**, graphics module **1032**, text input module **1034**, GPS module **1035**, and browser module **1047**, map module **1054** may be used to receive, display, modify, and store maps and data associated with maps (e.g., driving directions; data on stores and other points of interest at or near a particular location; and other location-based data) in accordance with user instructions.

[0168] In conjunction with touch screen **1012**, display system controller **1056**, contact module **1030**, graphics module **1032**, audio circuitry **1010**, speaker **1011**, RF circuitry **1008**, text input module **1034**, e-mail client module **1040**, and browser module **1047**, online video module **1055** includes instructions that allow the user to access, browse, receive (e.g., by streaming and/or download), play back (e.g., on the touch screen or on an external, connected display via external port **1024**), send an e-mail with a link to a particular online video, and otherwise manage online videos in one or more file formats, such as H.264. In some embodiments, instant messaging module **1041**, rather than e-mail client module **1040**, is used to send a link to a particular online video.

[0169] FIG. **11** illustrates a portable electronic device **1100** that may be powered by one or more of the batteries described above with reference to FIGS. **1-8**. Touch screen **1012** may display one or more graphics, also referred to herein as graphical representations, icons, etc., within user interface (UI) **1100**. UI **1100** can include a graphical user interface (GUI). In this embodiment, as well as others described below, a user may select one or more of the graphics by making a gesture on the graphics, for example, with one or more fingers

1102 (not drawn to scale in the Figure) or one or more styluses **1103** (not drawn to scale in the figure).

[0170] Device **1100** may also include one or more physical buttons, such as "home" or menu button **1104**. As described previously, menu button **1104** may be used to navigate to any application **1036** in a set of applications that may be executed on device **1000**. Alternatively, in some embodiments, the menu button is implemented as a soft key in a graphics user interface (GUI) displayed on touch screen **1012**.

[0171] In one embodiment, device **1000** includes touch screen **1012**, menu button **1104**, push button **1106** for powering the device on/off and locking the device, volume adjustment button(s) **1108**, Subscriber Identity Module (SIM) card slot **1110**, head set jack **1112**, and docking/charging external port **1024**. Push button **1106** may be used to turn the power on/off on the device by depressing the button and holding the button in the depressed state for a predefined time interval; to lock the device by depressing the button and releasing the button before the predefined time interval has elapsed; and/or to unlock the device or initiate an unlock process. In an alternative embodiment, device **1000** also may accept verbal input for activation or deactivation of some functions through microphone **1013**.

[0172] It should be noted that, although many of the examples herein are given with reference to optical sensor/camera **1064** (on the front of a device), a rear-facing camera or optical sensor that is pointed opposite from the display may be used instead of or in addition to an optical sensor/camera **1064** on the front of a device.

Example Computer System

[0173] FIG. **12** illustrates an example computer system **1200** that may be powered by one or more of the batteries described above with reference to FIGS. **1-8**. In different embodiments, computer system **1200** may be any of various types of devices, including, but not limited to, a personal computer system, desktop computer, laptop, notebook, tablet, slate, pad, or netbook computer, cell phone, smartphone, PDA, portable media device, mainframe computer system, handheld computer, workstation, network computer, a camera or video camera, a set top box, a mobile device, a consumer device, video game console, handheld video game device, application server, storage device, a television, a video recording device, a peripheral device such as a switch, modem, router, or in general any type of computing or electronic device.

[0174] Various embodiments of one or more functional components of an electronic device, a process for fabricating a lithium battery, etc., as described herein, may be executed in one or more computer systems **1200**, which may interact with various other devices. Note that any component, action, or functionality described above with respect to FIG. **1-11** may be implemented on one or more computers configured as computer system **1200** of FIG. **12**, according to various embodiments. In the illustrated embodiment, computer system **1200** includes one or more processors **1210** coupled to a system memory **1220** via an input/output (I/O) interface **1230**. Computer system **1200** further includes a network interface **1240** coupled to I/O interface **1230**, and one or more input/output devices **1250**, such as cursor control device **1260**, keyboard **1270**, and display(s) **1280**. In some cases, it is contemplated that embodiments may be implemented using a single instance of computer system **1200**, while in other embodiments multiple such systems, or multiple nodes making up computer system **1200**, may be configured to host different portions or instances of embodiments. For example, in one embodiment some elements may be implemented via one or more nodes of computer system **1200** that are distinct from those nodes implementing other elements.

[0175] System memory **1220** may be configured to store camera control program instructions **1222** and/or voice communication control data accessible by processor **1210**. In various embodiments, system memory **1220** may be implemented using any suitable memory technology, such as static random access memory (SRAM), synchronous dynamic RAM (SDRAM), nonvolatile/Flash-type memory, or any other type of memory. In the illustrated embodiment, program instructions **1222** may be configured to implement a point-to-point voice communication application incorporating any of the functionality described above. Additionally, program instructions **1222** of memory **1220** may include any of the information or data structures described above. In some embodiments, program instructions and/or data may be received, sent or stored upon different types of computer-accessible media or on similar media separate from system memory **1220** or computer system **1200**. While computer system **1200** is described as implementing the functionality of functional blocks of previous Figures, any of the functionality described herein may be implemented via such a computer system.

[0176] In one embodiment, I/O interface **1230** may be configured to coordinate I/O traffic between processor **1210**, system memory **1220**, and any peripheral devices in the device, including network interface **1240** or other peripheral interfaces, such as input/output devices **1250**. In some embodiments, I/O interface **1230** may perform any necessary protocol, timing or other data transformations to convert data signals from one component (e.g., system memory **1220**) into a format suitable for use by another component (e.g., processor **1210**). In some embodiments, I/O interface **1230** may include support for devices attached through various types of peripheral buses, such as a variant of the Peripheral Component Interconnect (PCI) bus standard or the Universal Serial Bus (USB) standard, for example. In some embodiments, the function of I/O interface **1230** may be split into two or more separate components, such as a north bridge and a south bridge, for example. Also, in some embodiments some or all of the functionality of I/O interface **1230**, such as an interface to system memory **1220**, may be incorporated directly into processor **1210**.

[0177] Network interface **1240** may be configured to allow data to be exchanged between computer system **1200** and other devices attached to a network **1285** (e.g., carrier or agent devices) or between nodes of computer system **1200**. Network **1285** may in various embodiments include one or more networks including but not limited to Local Area Networks (LANs) (e.g., an Ethernet or corporate network), Wide Area Networks (WANs) (e.g., the Internet), wireless data networks, some other electronic data network, or some combination thereof. In various embodiments, network interface **1240** may support communication via wired or wireless general data networks, such as any suitable type of Ethernet network, for example; via telecommunications/telephony networks such as analog voice networks or digital fiber communications networks; via storage area networks such as Fibre Channel SANs, or via any other suitable type of network and/or protocol.

[0178] Input/output devices **1250** may, in some embodiments, include one or more display terminals, keyboards, keypads, touchpads, scanning devices, voice or optical recognition devices, or any other devices suitable for entering or accessing data by one or more computer systems **1200**. Multiple input/output devices **1250** may be present in computer system **1200** or may be distributed on various nodes of computer system **1200**. In some embodiments, similar input/output devices may be separate from computer system **1200** and may interact with one or more nodes of computer system **1200** through a wired or wireless connection, such as over network interface **1240**.

[0179] As shown in FIG. **12**, memory **1220** may include program instructions **1222**, which may be processor-executable to implement any element or action described above. In one embodiment, the program instructions may implement the methods described above. In other embodiments, different elements and data may be included. Note that data may include any data or information described above.

[0180] The methods described herein, e.g., the method described in FIG. **9** and corresponding paragraphs, may be implemented via software, hardware, or a combination thereof in different embodiments (e.g., automated assembly of a battery). In addition, the order of execution of some the blocks of the methods (e.g., the method described in FIG. **9**) may be changed, and various elements may be added, reordered, combined, omitted, modified, etc.

[0181] Various modifications and changes may be made as would be obvious to a person skilled in the art having the benefit of this disclosure. The various embodiments described herein are meant to be illustrative and not limiting. Many variations, modifications, additions, and improvements are possible. Accordingly, plural instances may be provided for components described herein as a single instance. Other allocations of functionality are envisioned and may fall within the scope of claims that follow. Finally, structures and functionality presented as discrete components in the example configurations may be implemented as a combined structure or component. These and other variations, modifications, additions, and improvements may fall within the scope of embodiments as defined in the claims that follow.

What is claimed is:

1. A battery, comprising:

a first electrode;

a second electrode; and

a porous layer positioned between the first electrode and the second electrode, wherein the porous layer resists dendrite growth from the first electrode through the porous layer to the second electrode and permits ion transport through the porous layer from the first electrode to the second electrode.

2. The battery of claim **1**, wherein:

the porous layer comprises a porous layer that includes a plurality of pores sized to permit ionic transport through the porous layer and to resist dendrite growth through the porous layer.

3. The battery of claim **1**, wherein the first electrode comprises lithium.

4. The battery of claim **1**, further comprising at least one battery separator coupled to at least one side of the porous layer, the at least one battery separator configured to inhibit ionic transport between the electrodes of the battery responsive to a temperature of the at least one battery separator exceeding a temperature threshold.

5. The battery of claim **1**, wherein the porous layer has a thickness dimension that is less than or equal to approximately 20 microns.

6. The battery of claim **1**, wherein the battery comprises at least one solid electrolyte that is located on at least one side of the porous layer.

7. The battery of claim **6**, wherein:

the at least one solid electrolyte comprises a solid electrolyte layer that is applied to at least one side of the porous layer, such that the porous layer at least partially structurally supports the solid electrolyte layer; and

the porous layer is applied to at least one side of at least one of the electrodes.

8. The battery of claim **1**, wherein the first electrode comprises a first electrically conducting thin film and that includes lithium, the second electrode comprises a second electrically conducting thin film, and the porous layer comprises a porous thin film.

9. A method, comprising:

assembling a first electrode, a second electrode positioned opposite the first electrode and an electrolyte positioned between the first electrode and the second electrode;

providing a porous layer between the first electrode and the second electrode and contacting the electrolyte, wherein the porous layer is configured to permit ionic transport from the first electrode to the second electrode through the porous layer, and to resist one or more dendrites attach to the first electrode from extending from a first surface of the porous layer situated opposite the first electrode through the porous layer to a second surface of the proximate layer situated opposite the second electrode.

10. The method of claim **9**, wherein the porous layer comprises a plurality of pores that are sized to facilitate transport of ions that originate at the first electrode through the porous layer via the plurality of pores, and to resist one or more dendrites that originate at the first electrode from passing through the porous layer via the plurality of apertures.

11. The method of claim **9**, wherein the first electrode comprises lithium.

12. The method of claim **9**, wherein providing the porous layer between the first electrode and the second electrode comprises laminating at least the porous layer to at least one battery separator, wherein the at least one battery separator is configured to inhibit ion transport between the first electrode and the second electrode responsive to a temperature of the at least one battery separator exceeding a threshold temperature.

13. The method of claim **9**, wherein providing the porous layer between the first electrode and the second electrode comprises:

applying a solid electrolyte layer to at least one side of the porous layer, such that the porous layer at least partially structurally supports the solid electrolyte layer; and

subsequent to applying the solid electrolyte layer to the at least one side of the porous layer, applying the porous layer to at least one of the first electrode and the second electrode on at least one other side of the porous layer, wherein the solid electrolyte layer is to conduct ions between the first electrode and the second electrode via at least one portion of the porous layer.

14. The method of claim **13**, wherein applying the solid electrolyte layer to at least one side of the porous layer comprises performing at least one of:

laminating the solid electrolyte layer to at least one side of the porous layer;

depositing the solid electrolyte layer on at least one side of the porous layer; or

coating the solid electrolyte layer on at least one side of the porous layer.

15. The method of claim **9**, wherein providing the porous layer between the first electrode and the second electrode comprises laminating the porous layer to the first electrode or to the second electrode.

16. The method of claim **9**, wherein the porous layer comprises pores having a maximum pore diameter of approximately 200 nanometers.

17. A device comprising:

at least one functional component configured to consume electrical power; and

a battery configured to provide electrical power support to the at least one functional component, wherein the battery includes a porous layer situated between a first electrode and a second electrode and configured to permit ionic transport through the porous layer and to resist dendrite growth through the porous layer of one or more dendrites that attach to a first electrode of the battery.

18. The portable electronic device of claim **17**, wherein the porous layer comprises a porous anodic aluminum oxide (AAO) layer that comprises a plurality of pores.

19. The portable electronic device of claim **17**, wherein the porous layer comprises a plurality of pores that extend from one face of the porous layer to an opposite face of the porous layer and wherein the diameter of each pore is at least approximately 20 nanometers and less than or equal to approximately 200 nanometers.

20. The portable electronic device of claim **17**, wherein:

the battery comprises at least one battery separator coupled to at least one side of the porous layer; and

the at least one battery separator is configured to inhibit ionic transport between the first and second electrodes of the battery responsive to a temperature of the at least one battery separator exceeding a threshold temperature.

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